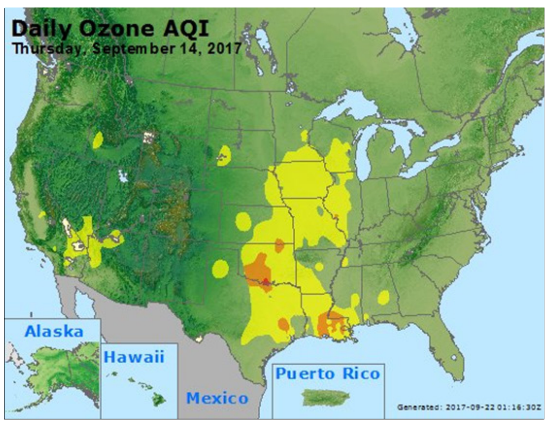
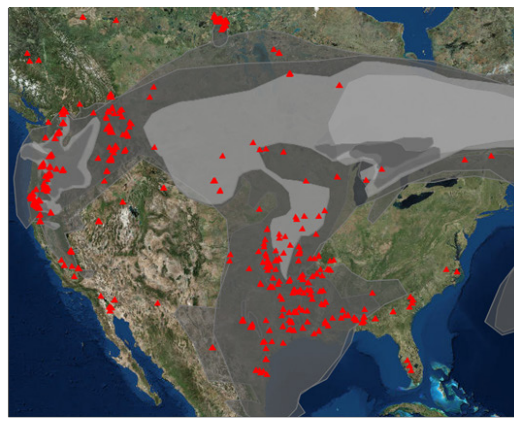
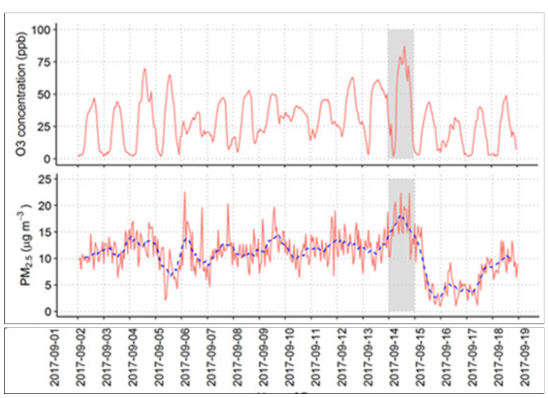
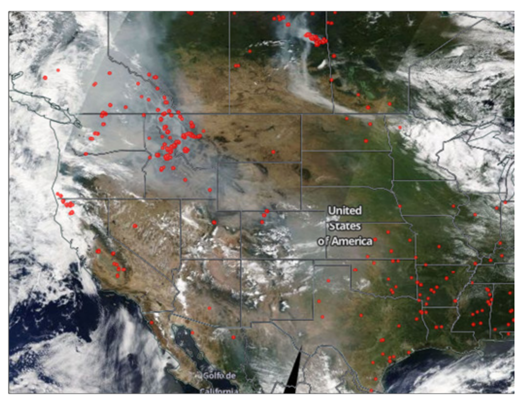
Tier 1 and 2 Smoke Exceptional Event Analyses for Louisiana, September 14, 2017









Final Report Prepared for

Louisiana Department of Environmental Quality
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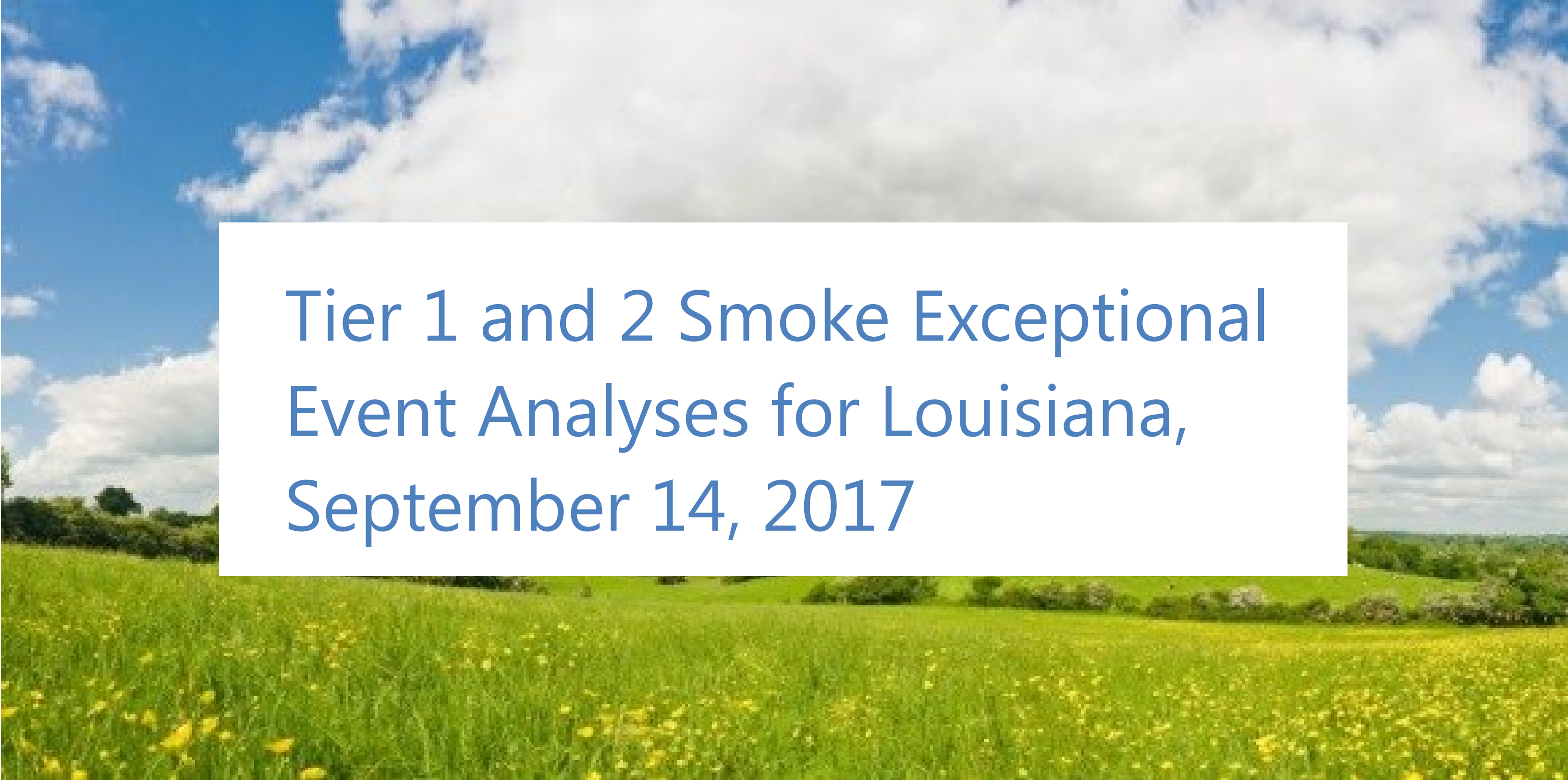

Tier 1 and 2 Smoke Exceptional Event Analyses for Louisiana, September 14, 2017

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List of Terms

Term	Definition
AGL	Above ground level
AIRS	Atmospheric Infrared Sounder
AOD	Aerosol Optical Depth
AQI	Air Quality Index
AQS	Air Quality System
AVHRR	Advanced Very High Resolution Radiometer
CATS	Cloud-Aerosol Transport System
EPA	U.S. Environmental Protection Agency
FACTS	Forest Service Activity Tracking System
GeoMAC	Geospatial Multi-Agency Coordination
GOES	Geostationary Operational Environmental Satellite system
HMS	NOAA's Hazard Mapping System
HRRR	NOAA's High-Resolution Rapid Refresh model
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory
ISS	International Space Station
LIDAR	Light Detection and Ranging
m	meters
MODIS	Moderate Resolution Imaging Spectroradiometer
NAAQS	National Ambient Air Quality Standards
NAM	North American Mesoscale Forecast System
NOAA	National Oceanic and Atmospheric Administration
OMI	Ozone Monitoring Instrument
NASF	National Association of State Foresters
NEI	National Emissions Inventory
NOAA	National Oceanic and Atmospheric Administration
PAMS	Photochemical Assessment Monitoring Stations
Q/d	Emissions/distance ratio
TNMOC	Total non-methane organic compounds
UTC	Coordinated Universal Time
VIIRS	Visible Infrared Imaging Radiometer Suite
VOC	Volatile organic compounds

Executive Summary

On September 14, 2017, Baton Rouge experienced an unusual, area-wide episode of elevated ambient ozone; during this episode, the 2015 8-hr ozone National Ambient Air Quality Standards (NAAQS) thresholds were exceeded at multiple sites, including the Dutchtown monitoring site. The exceedance at Dutchtown could lead to an ozone nonattainment designation for the Baton Rouge area. Satellite observations and air quality modeling suggest that this ozone exceedance was influenced by wildfire smoke that was transported to Baton Rouge from large wildfires burning in the northwestern United States, including Washington, Oregon, Idaho, and Montana, and in California. The EPA Exceptional Event Rule (U.S. Environmental Protection Agency, 2016a) allows air agencies to omit air quality data from the design value calculation if it can be demonstrated that the measurement in question was caused by an exceptional event. This report describes analyses that help to establish a clear causal relationship between wildfire smoke and the September 14, 2017, ozone exceedance at the Dutchtown Monitoring Site.

The analyses we conducted provide evidence supportive of smoke impacts on ozone concentrations in Baton Rouge. We show that (1) substantial amounts of smoke were transported from wildfires in the northwestern United States across the central United States to Louisiana in the days leading up to September 14, 2017, (2) smoke aloft was transported to the surface on September 14, 2017, and (3) smoke impacted ground-level pollution measurements in the Baton Rouge area on September 14, 2017. Sources of evidence used in these analyses include air quality monitor data, satellite data, air trajectory analysis, and agency fire reports.

EPA guidance for exceptional event demonstrations (U.S. Environmental Protection Agency, 2016b) provides a three-tiered approach; depending on the complexity of the event, increasingly involved information may be required to demonstrate a causal relationship between wildfire smoke and an exceedance. Here, we provide the results of analyses conducted to address Tier 1 and Tier 2 exceptional event demonstration requirements. Our findings from these analyses are summarized in Table ES-1. The results are supportive of a Tier 3 exceptional event demonstration.

These analyses show that smoke was transported from wildfires in the northwestern United States to Louisiana over the days leading up to September 14. They additionally show that air quality at the Dutchtown monitor was impacted by wildfire smoke on that day. Combined with additional evidence, such as meteorological regression modeling, our results provide key evidence to support smoke impacts on ozone concentrations in Baton Rouge on September 14, 2017.

Table ES-1. Summary of tier-specific analyses for smoke/ozone exceptional events and the analysis findings.

Tier	Requirements	Finding
1	• Comparison of fire-influenced exceedance with historical concentrations • Key factor: Evidence that fire and monitor meet one of the following criteria: – Seasonality differs from typical season, or – Ozone concentrations are 5-10 ppb higher than non-event-related concentrations • Evidence of transport of fire emissions to monitor: – Trajectories of fire emissions, or – Satellite images and supporting evidence from surface measurements	• The September 14. 2017, ozone exceedance occurred during typical ozone season. • Trajectories and satellite images and data support long-range smoke transport into the area. • Trajectories, ceilometer mixing height measurements, and radiosonde data indicate vertical mixing and transport to the surface from the elevation at which smoke was present.
2	• All Tier 1 requirements • Key Factor #1: Fire emissions and distance of fires (Q/d > 100) • Key Factor #2: Comparison of the event-related ozone concentration with non-event-related high ozone concentrations (>99th percentile over five years or top four highest daily ozone measurement) • Evidence that fire emissions affected the monitor (at least one of the following): – Visibility impacts – Changes in supporting measurements – Satellite NO_x enhancements – Differences in spatial/temporal patterns	• The Q/d was well below 100. • Ozone concentration was >99th percentile over five years and was the top measurement for the year. • Surface $PM_{2.5}$, NO_x, and CO concentrations showed elevated concentrations and/or changes in diurnal profile consistent with smoke impacts.

1. Introduction

On September 14, 2017, the Baton Rouge area of Louisiana experienced area-wide elevated ozone measurements. Six out of nine monitors measured concentrations that exceeded the daily maximum 8-hr average ozone standard of 70 ppb on that day, and the other three monitors in the area also showed evidence of higher than usual ozone. With the September 14 exceedance, the ozone design value for the Dutchtown site in Baton Rouge for 2015–2017 exceeded the national standard of 70 ppb. Had ozone concentrations at the site not exceeded the standard on September 14, the design value would have been within the standard. Therefore, the September 14 exceedance is of regulatory significance.

Under EPA rules, data for which exceptional event impacts have been demonstrated may be omitted from design value calculations. Evidence presented in this report suggests that smoke from wildfires contributed to the exceedance observed on September 14. During the two weeks leading up to September 14, large wildfires were active in the northwestern United States as well as in Saskatchewan, Canada. Significant quantities of smoke were released from these fires and transported across the northern and central United States. Air mass transport patterns leading up to September 14 brought smoke from the northwestern United States to Louisiana. That smoke was present at ground level on September 14, and it impacted local air quality.

This report describes the results of analyses by Sonoma Technology, Inc., that support a causal relationship between wildfire smoke and the Dutchtown exceedance on September 14. In Section 2, we summarize the EPA guidance for demonstrating a wildfire smoke-related exceptional event and describe the analyses conducted in accordance with that guidance. Section 3 describes the analytical approach used for each analysis as well as the results. Section 4 summarizes the findings from this work. The appendices provide additional supporting information. Appendix A contains historical context plots for ozone measurements made at all monitor locations in Baton Rouge. Appendix B provides additional supporting measurement plots, including depictions of ratios of VOC/NO_x and CO/NO_x, and timeseries plots for speciated VOC measurements. Appendix C describes the results of coarse resolution photochemical modeling that provide qualitative evidence that wildfire smoke impacted air quality in Louisiana. Appendix D summarizes the meteorological conditions leading up to the September 14 event.

2. Analysis Approach

EPA exceptional event guidance includes a three-tiered approach for exceptional events demonstrations due to wildfire(s); see **Table 1** for a summary. Tier 1 and Tier 2 analyses are provided for cases where there is a clear or obvious relationship between a fire (or multiple fires) and an ozone exceedance. Tier 1 analyses can be used when an exceedance occurred during a time of year when ozone concentrations are typically low or when the concentration measured during an event is substantially higher in magnitude (5-10 ppb) than observed non-event concentrations. Tier 2 analyses are appropriate for cases when a high-emitting fire occurred near the impacted monitor, and smoke transport from the fire to the monitor can be clearly shown. Tier 3 analyses are used when the relationship between smoke from a wildfire(s) and an ozone exceedance is more complicated, or is more difficult to demonstrate using Tier 1 and Tier 2 data analysis tools and methods. Table 1 summarizes the analyses required in each tier. Within the scope of the work described here, we conducted Tier 1 and Tier 2 exceptional event analyses.

Table 1. Summary of tier-specific analyses for smoke/ozone exceptional events.

Tier	Requirements
1	• Comparison of fire-influenced exceedance with historical concentrations • Key factor: Evidence that fire and monitor meet one of the following criteria: – Seasonality differs from typical season, or – Ozone concentrations are 5-10 ppb higher than non-event-related concentrations • Evidence of transport of fire emissions to monitor: – Trajectories of fire emissions, or – Satellite images and supporting evidence from surface measurements
2	• All Tier 1 requirements • Key Factor #1: Fire emissions and distance of fires • Key Factor #2: Comparison of the event-related ozone concentration with non-event-related high ozone concentrations (>99th percentile over five years or top four highest daily ozone measurements) • Evidence that fire emissions affected the monitor (at least one of the following): – Visibility impacts – Changes in supporting measurements – Satellite NO_x enhancements – Differences in spatial/temporal patterns
3	• All Tier 2 requirements • Evidence of fire emissions effects on monitor: – Multiple analyses from those listed for Tier 2 • Evidence of fire emissions transport to the monitor: – Trajectory or satellite plume analysis, and – Additional discussion of meteorological conditions • Additional evidence such as: – Comparison to ozone concentrations on matching (meteorologically similar) days – Statistical regression modeling – Photochemical modeling of smoke contributions to ozone concentrations

Within the tiered approach for wildfire exceptional event analysis, each tier has one or more key factors and additional supporting evidence that must be addressed by an exceptional event demonstration (**Table 2**). For Tier 1 analyses, the key factor recommended is to provide evidence of the unusual seasonality and/or higher magnitude of the monitored ozone concentration. In addition, Tier 1 analyses should provide evidence, using Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) trajectories and/or satellite imagery, that the wildfire emissions were transported to the affected monitor. We address the Tier 1 key factor in Section 3.1 of this report, and we provide evidence of smoke transport to the monitor in Sections 3.2, 3.3, and 3.4.

Tier 2 exceptional event analyses must provide evidence of two key factors, including assessment of the fire emissions and distance of fires to the affected monitoring site (Tier 2 Key Factor #1) and a comparison of the event-related ozone concentration with non-event-related high ozone concentrations (Tier 2 Key Factor #2). A Tier 2 exceptional event analysis should also provide evidence of transport of fire emissions from the monitor and evidence that the fire emissions affected the monitor. We address Tier 2 Key Factor #1 in Section 3.7 and Key Factor #2 in Section 3.1. We provide evidence that the smoke was transported to the site in Sections 3.2, 3.3, 3.4, and 3.5, and we show that the monitor was affected by fire emissions in Section 3.6.

We conducted Tier 1 and Tier 2 analyses following EPA's exceptional event guidance. These analyses focused on characterizing the meteorology, smoke, and air quality on the days/weeks leading up to September 14, 2017. The following specific analyses were performed:

- Developed figures that show the September 14 ozone concentrations in historical context for 2017 and for the past five years
- Compiled maps of ozone concentrations in the area, smoke plumes, and fire locations from satellite data
- Showed the air flow patterns via HYSPLIT modeling, and identified where the air flow intersected with smoke plumes or passed over or near fires
- Provided maps showing satellite retrievals of NO_x, Aerosol Optical Depth (AOD), and CO
- Assessed vertical transport of smoke using satellite-observed aerosol vertical profiles and ceilometer mixing height retrievals
- Developed a figure showing whether the diurnal pattern of NO_x, ozone, and volatile organic compound (VOC)/NO_x ratios on September 14 were different from typical patterns in August-September
- Acquired and analyzed local $PM_{2.5}$, VOC, CO, NO_x, and reactive oxides of nitrogen (NO_y) to identify whether there were unusual concentrations of species or of CO/NO_x ratios that would indicate smoke influences
- Quantified total fire emissions and calculate emissions/distance ratio (Q/d) for nearby fires

In Section 3 of this report, we provide the results of the Tier 1 and Tier 2 analyses described above.

Table 2. Evidence for Tier 1 and Tier 2 analyses provided in this report.

Tier	Element	Section of This Report (Analysis Type)
Tier 1	Key factor: Seasonality and/or distinctive level of the monitored ozone concentration compared to non-event-related concentrations	Section 3.1 (Ozone historical context)
	Evidence of smoke transport to the monitor	Sections 3.2 (Maps of ozone, fire, and smoke), 3.3 (HYSPLIT Trajectories), 3.4 (Satellite data), 3.5 (Evidence of vertical transport), and Appendix D
Tier 2	Key Factor #1: fire emissions and distance of fires to the site	Section 3.7 (Q/d)
	Key Factor #2: comparison of event-related ozone with non-event related high ozone	Section 3.1 (Ozone historical context)
	Evidence that the smoke was transported to the site	Sections 3.2 (Maps of ozone, fire, and smoke), 3.3 (HYSPLIT trajectories), 3.4 (Satellite data), and 3.5 (Evidence of vertical transport)
	Evidence that the fire emissions affected the monitor	Section 3.6 (Other supporting pollutant trends and diurnal patterns) and Appendix B

3. Analysis Results

3.1 Ozone Historical Context

Figure 1 shows the locations of the Baton Rouge area monitoring sites; sites that recorded an ozone exceedance on September 14, 2017, are marked in red. Air quality data collected at these sites were downloaded using the Air Quality System (AQS) Web Application for 2013-2017, which retrieves data directly from the EPA AQS database (www.epa.gov/aqs). Parameters retrieved include hourly CO, NO_x, ozone, and $PM_{2.5}$, 24-hr Photochemical Assessment Monitoring Stations (PAMS) VOC, and 3-hr PAMS VOC. AQS data can be used to meet the Tier 1 and Tier 2 requirements for comparison of a fire-influenced ozone exceedance with historical concentrations.

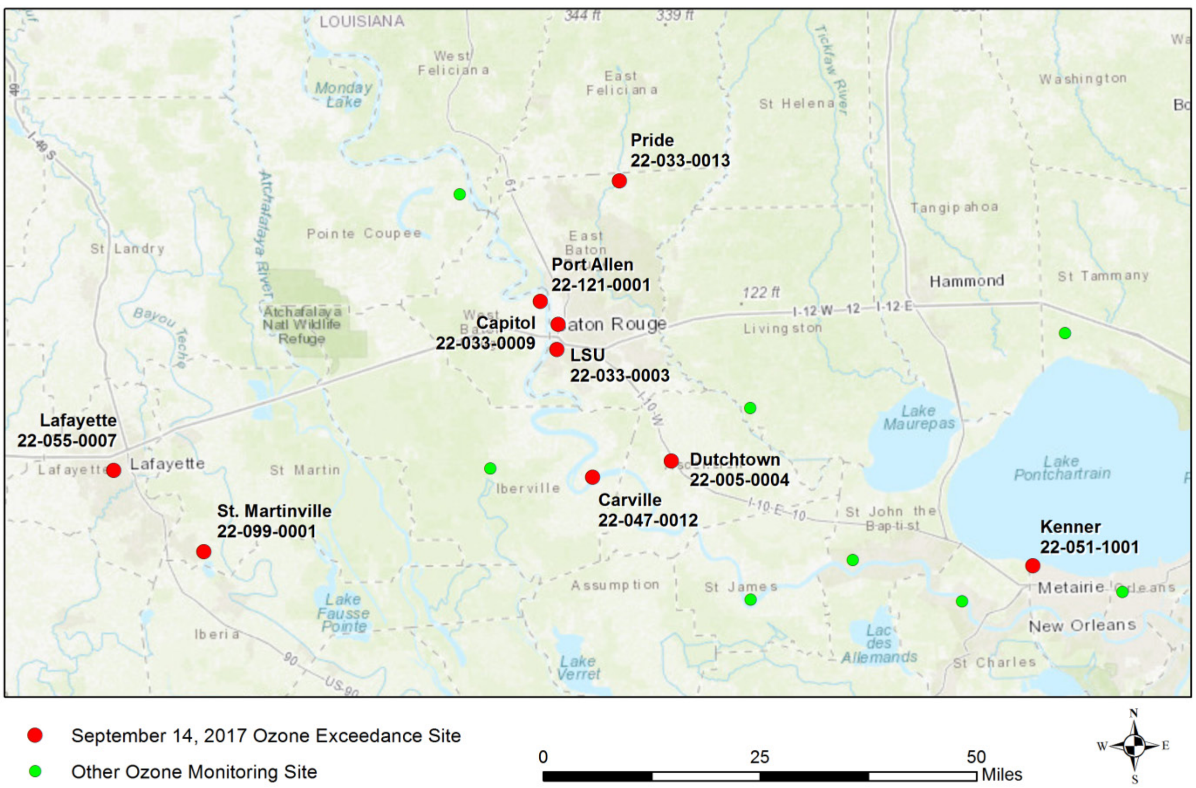

Figure 1. Locations of the Baton Rouge ozone monitoring sites. September 14, 2017, ozone exceedance sites are shown by red circles.

3.1.1 Regulatory Significance

Annual design values are computed by the EPA to reflect a location's air quality status in relation to the National Ambient Air Quality Standards (NAAQS). The 8-hr ozone design value is the three-year average of the fourth-highest daily maximum 8-hr ozone concentration (40 CFR Part 50, Appendix U). The ozone design value for the Dutchtown site is 71 ppb for 2015–2017 when all data are included (Table 3). Table 4 shows that the highest daily maximum 8-hr ozone concentration for Dutchtown in 2017 was on September 14; if the day is omitted, the 2017 ozone design value will drop to 70 ppb and will comply with the NAAQS.

Table 3. Ozone design value in Baton Rouge (N/A indicates that the monitor did not meet the completeness criteria described in 40 CFR Part 50, Appendix U).

AQS Site Code	Site Name	Ozone 4th Highest 2015	Ozone 4th Highest 2016	Ozone 4th Highest 2017	Design Value
22-005-0004	Dutchtown	74	71	68	71
22-047-0012	Carville	75	N/A	62	N/A
22-033-0003	LSU	73	68	70	70
22-033-0009	Capitol	69	61	73	68
22-121-0001	Port Allen	66	66	70	67
22-033-0013	Pride	62	N/A	71	N/A
22-077-0001	New Roads	69	65	68	67
22-047-0009	Bayou Plaquemine	69	64	67	N/A
22-063-0002	French Settlement	70	67	68	68

Table 4. Ozone design value comparison at the Dutchtown monitoring site. The asterisk (*) marks the September 14, 2017, ozone exceedance.

	2015	2016	2017
Highest	82	74	76*
Second Highest	80	73	75
Third Highest	75	72	69
Fourth Highest	74	71	68
Fifth Highest	71	66	67
Design Value Including All Measurements		**71**	
Design Value Excluding September 14, 2017 Event(*)		**70**	

3.1.2 Ozone Historical Data Comparisons

The maximum daily 8-hr ozone average concentration of 76 ppb measured at the Dutchtown monitoring site was the highest measured ozone concentration in 2017. **Figure 2** shows the September 14 concentration value of 76, with only one other day in the year exceeding the 70 ppb NAAQS threshold.

Figures 3 and 4 provide historical context of ozone concentrations at the Dutchtown site by showing maximum 8-hr ozone concentration data from 2013 to 2017. Figure 3 shows that the Dutchtown monitoring site measured concentrations of 76 ppb or higher on only four days in the past five years, one of which was September 14, 2017. Figure 4 shows that elevated ozone historically occurs between April (91st day) and the end of October (304th day). Although the September 14, 2017, exceedance occurred during the normal April-October ozone seasons, it ranks above the 99th percentile for the all data collected from 2013 to 2017 at Dutchtown.

The evidence provided by these plots is relevant to key factors for Tier 1 and Tier 2 exceptional event demonstrations. The exceedance on September 14, 2017, does not satisfy the key factor for a Tier 1 event because it occurred during the normal ozone season (April-October) and because it was not 5-10 ppb higher than non-event-related concentrations. However, it substantially exceeds the 5-year 99^{th} percentile of ozone concentrations measured at the Dutchtown site, satisfying Key Factor #2 for Tier 2 exceptional event demonstrations. Key Factor #1 for Tier 2 is discussed in Section 3.7.

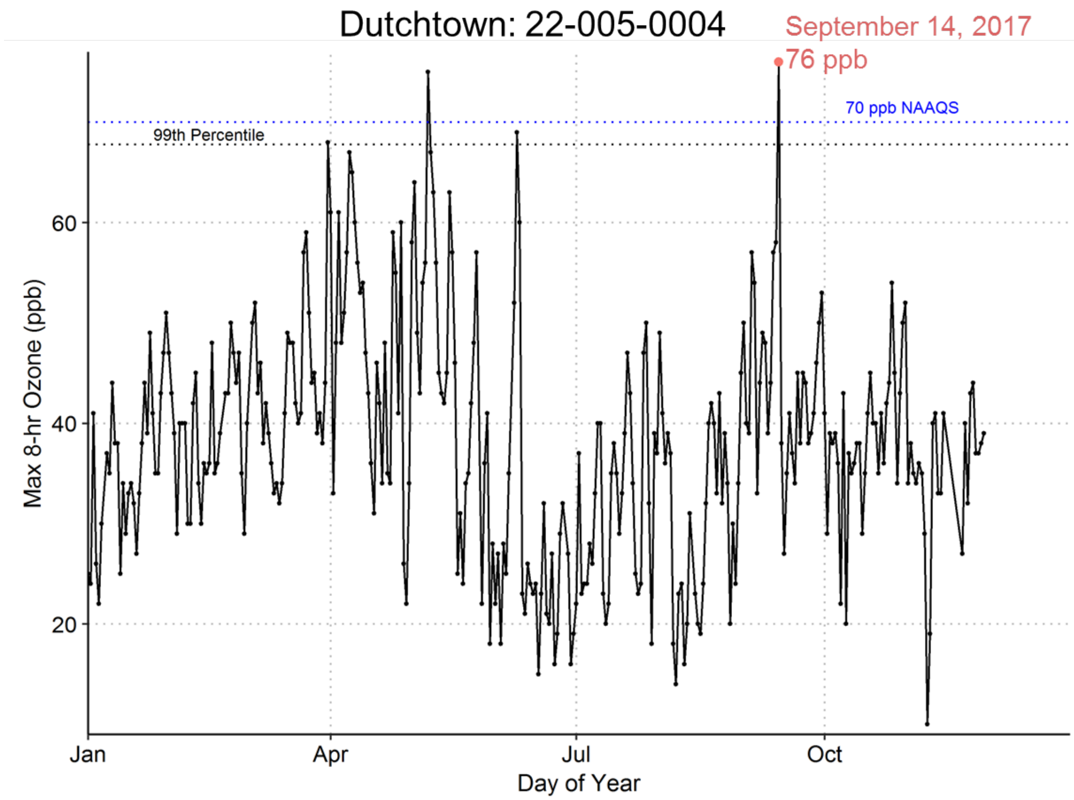

Figure 2. Daily maximum 8-hr ozone concentrations (ppb) at the Dutchtown monitoring site in 2017. The black dotted line indicates the 99th percentile for 2013 through 2017 at the Dutchtown monitoring site.

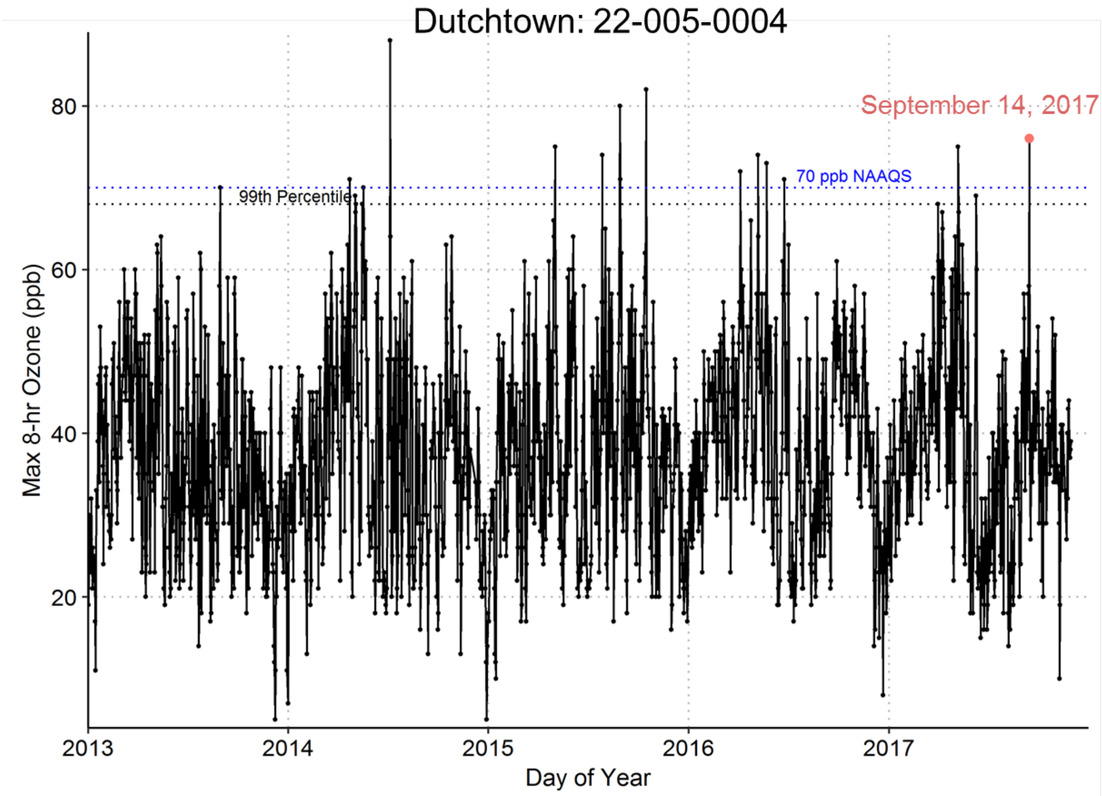

Figure 3. Daily maximum 8-hr ozone concentrations (ppb) at the Dutchtown monitoring site over the past five years (2013-2017).

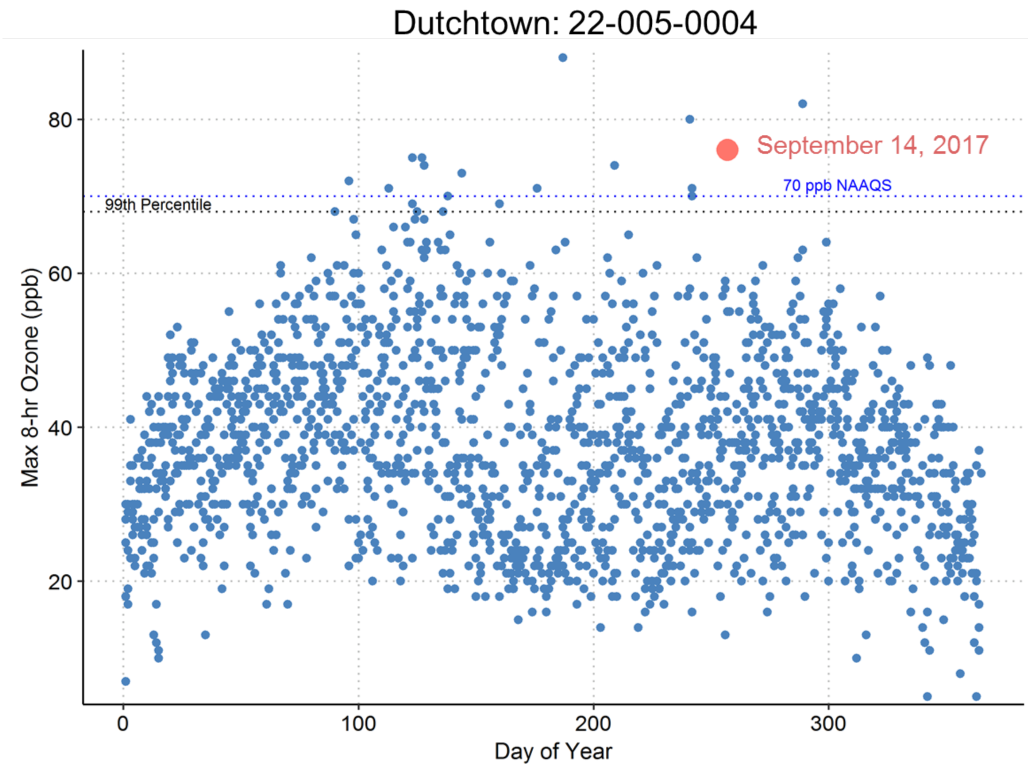

Figure 4. Daily maximum 8-hr ozone concentrations (ppb) by day of year at the Dutchtown monitoring site for 2013 through 2017. The typical ozone season is between the beginning of April (Day 91) and end of October (Day 304).

Ozone concentrations were elevated at sites across Baton Rouge on September 14 (**Figure 5**), indicating that Baton Rouge was impacted by an area-wide ozone event. **Table 5** depicts the 5-year percentile of daily maximum 8-hr ozone concentration on September 14, 2017, for ozone monitors in the Baton Rouge area. Eight out of nine monitors in the Baton Rouge area recorded daily maximum 8-hr ozone concentrations above the 99th percentile on September 14, 2017, indicating a rare ozone event on this date. Between 2013 and 2017, the September 14, 2017, exceedance was the only exceedance recorded at the Pride monitoring site between July and the end of the year, further underscoring the exceptional nature of this ozone exceedance. Historical ozone plots for all other Baton Rouge sites, similar to the Dutchtown plots shown in Figures 3 and 4, can be found in Appendix A.

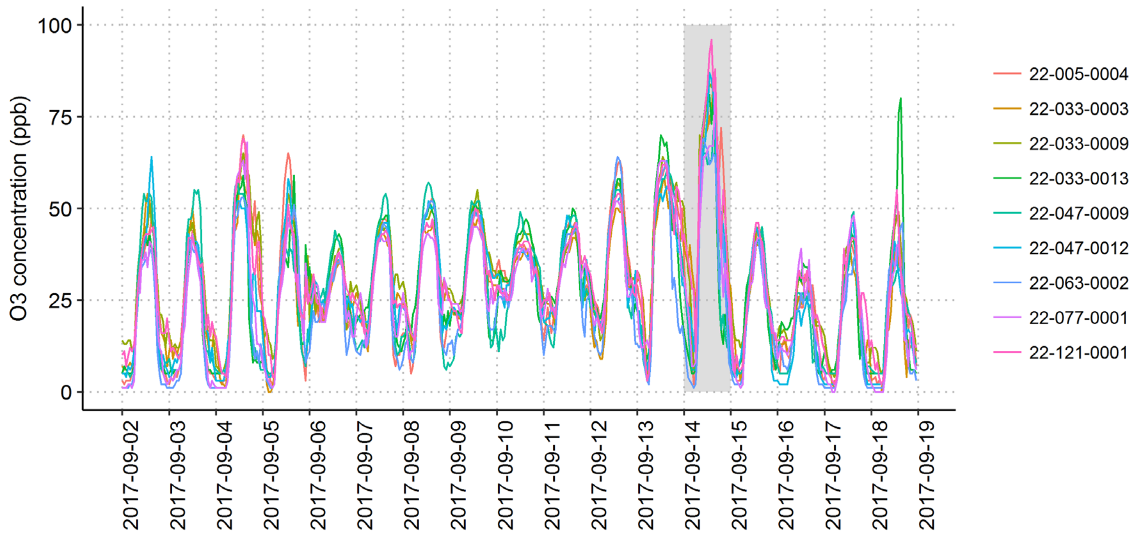

Figure 5. One-hour ozone concentrations (ppb) at all ozone monitoring sites in Baton Rouge, September 2 to September 18, 2017.

Table 5. Five-year percentile of daily maximum 8-hr ozone concentrations on September 14, 2017, for ozone monitors in the Baton Rouge area.

AQS Site Code	Site Name	5-Year Percentile
22-005-0004	Dutchtown	99.8
22-033-0003	LSU	99.3
22-033-0009	Capitol	99.9
22-033-0013	Pride	99.9
22-047-0009	Bayou Plaquemine	99.0*
22-047-0012	Carville	99.5
22-063-0002	French Settlement	97.9*
22-077-0001	New Roads	99.1*
22-121-0001	Port Allen	99.9

* Did not record an ozone exceedance on September 14, 2017.

These analyses show that, while not eligible for Tier 1, ozone concentrations measured on September 14, 2017, were unusually high at sites throughout Baton Rouge. The results also show that the September 14 event satisfies Key Factor #2 for Tier 2 exceptional events.

3.2 Ozone, Fire, and Smoke Maps

We produced maps of ozone AQI, $PM_{2.5}$ AQI, active fire and smoke detections from satellite, and visible satellite imagery that show the transport of smoke to Louisiana on September 14, 2017, and that show that high ozone across multiple states corresponded with the presence of wildfire smoke.

3.2.1 Ozone and $PM_{2.5}$ AQI Maps

From September 11 through September 14, high ground-level ozone concentrations increased in the central and southern United States (**Figure 6**), peaking on September 14 in several locations. On September 11, higher ozone concentrations are seen in Oklahoma and central Texas. This ozone develops and moves southward on September 12. On September 13, the area impacted by high ozone concentrations covers an area from Iowa to Texas and extends eastward into Louisiana from Texas. On September 14, the region of high observed ozone expands over a larger portion of the South and Midwest, and high ozone concentrations are present at Baton Rouge.

The same pattern of expanding pollutant concentrations over the Midwest and South is also seen in air quality index (AQI) plots for $PM_{2.5}$ (**Figure 7**). According to EPA guidance, "if plume arrival at a given location coincides with elevation of wildfire plume components (such as $PM_{2.5}$, CO, or organic and elemental carbon), those two pieces of evidence combined can show that smoke was transported from the event location to the monitor with the elevated O_3 concentration." In Sections 3.2.2, 3.2.3, and 3.4, we show that the elevated ozone and $PM_{2.5}$ concentrations observed in the Midwest and South, including Louisiana, corresponded with the arrival of a smoke plume from fires in the northwestern United States.

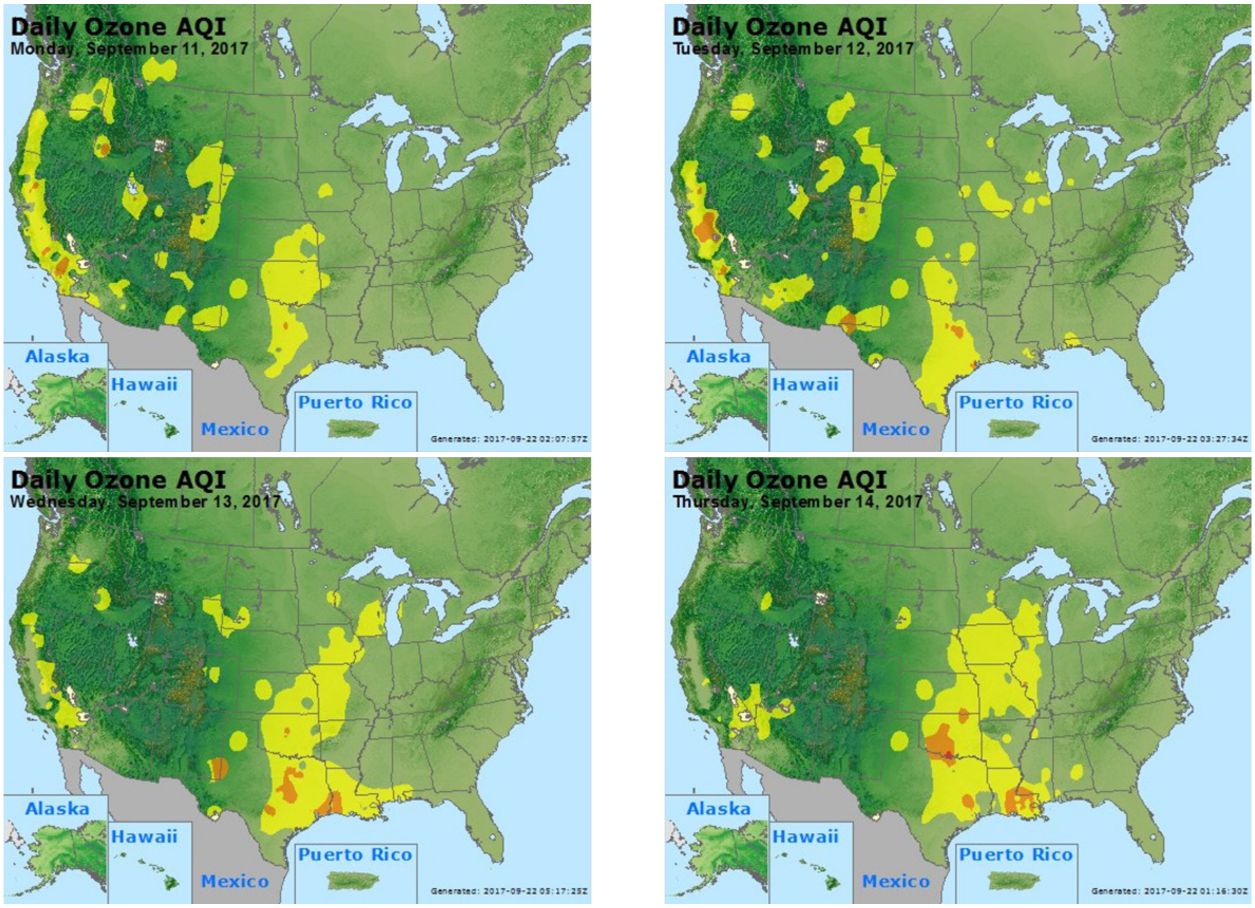

Figure 6. Daily ozone AQI from airnow.gov for September 11-14, 2017. Colors on the map indicate interpolated air quality observations. Yellow indicates Moderate air quality (AQI: 51-100), orange indicates Unhealthy for Sensitive Groups air quality (AQI: 101-150), and red indicates Unhealthy air quality (AQI: 151-200). Image source: EPA AirNow.

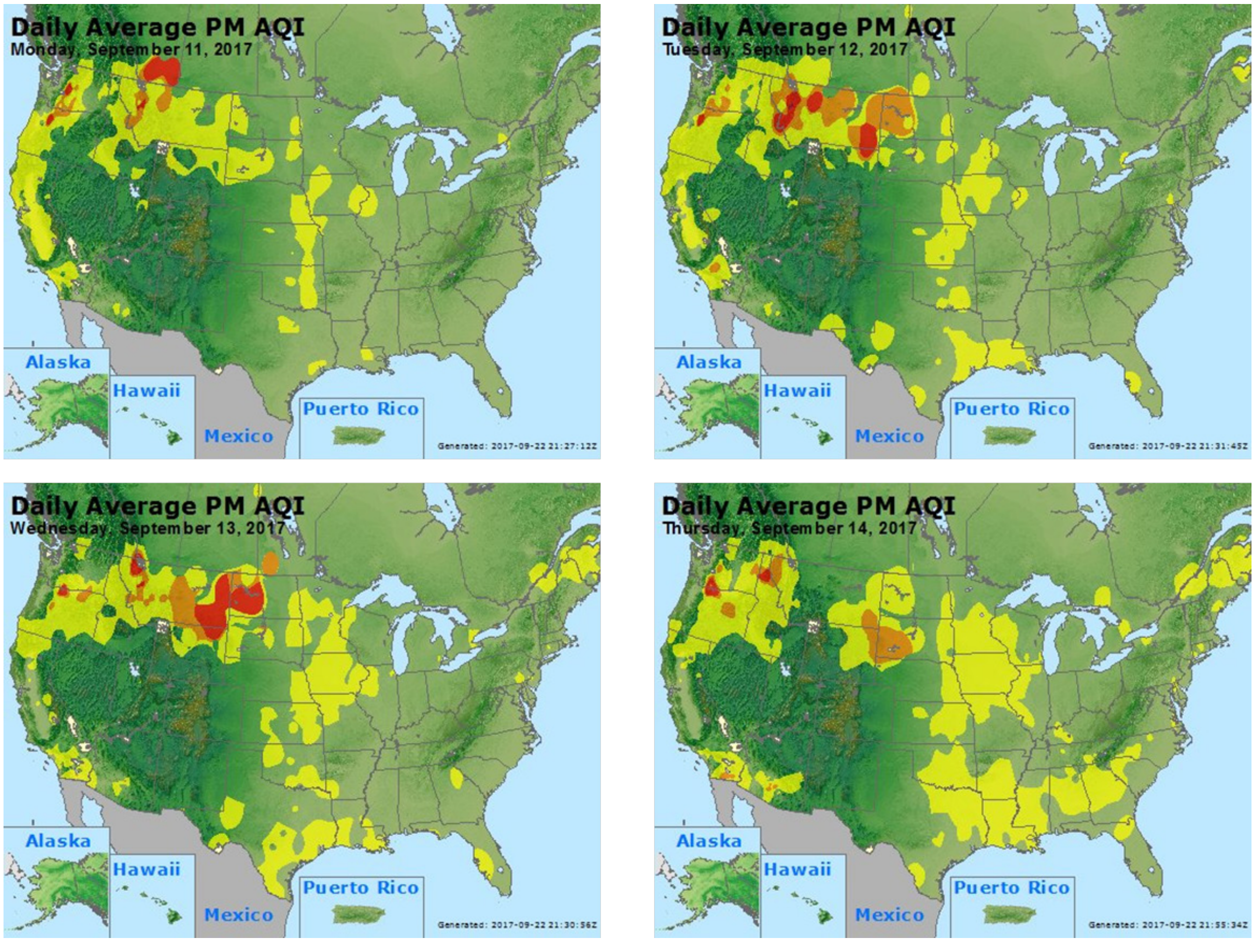

Figure 7. Daily $PM_{2.5}$ AQI from airnow.gov for September 11-14, 2017. Colors on the map indicate interpolated air quality observations. Yellow indicates Moderate air quality (AQI: 51-100), orange indicates Unhealthy for Sensitive Groups air quality (AQI: 101-150), and red indicates Unhealthy air quality (AQI: 151-200). Image source: EPA AirNow.

3.2.2 HMS Fire Detect and Smoke Plume Data

The National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) Fire and Smoke Product consists of

1. A daily fire detection product derived from three satellite data products[1] to spatially and temporally map fire locations at 1-km grid resolution, and
2. A daily smoke product derived from visible satellite imagery[2] that consists of polygons showing regions impacted by smoke.

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[1] The HMS fire detection product is developed using data from the Moderate Resolution Imaging Spectroradiometer (MODIS), Geostationary Operational Environmental Satellite system (GOES), Advanced Very High Resolution Radiometer (AVHRR) and Visible Infrared Imaging Radiometer Suite (VIIRS) satellite instruments.

[2] The HMS smoke product is derived from GOES-EAST and GOES-WEST visible satellite imagery.

HMS can be used to provide evidence of transport of fire emissions to a monitor as part of the Tier 1 analysis requirements discussed in the EPA's guidance. An advantage of HMS smoke plume data over other available satellite data is that HMS incorporates data from several environmental satellites. An additional advantage is that HMS data are created and reviewed by NOAA-trained analysts using animated imagery, allowing the analyst to identify instances where smoke is dispersed by transport, which can be challenging to recognize in a single visible image. Real-time HMS fire detection and smoke products, as well as a six-month archive of the products, are available on the NOAA Satellite and Information Service website (ospo.noaa.gov/products/land/hms.html). Users may download data as a GIS SHP, Google Earth KML, or JPG file. Figure 8 shows HMS smoke plume and fire detect data for September 11-14, 2017.

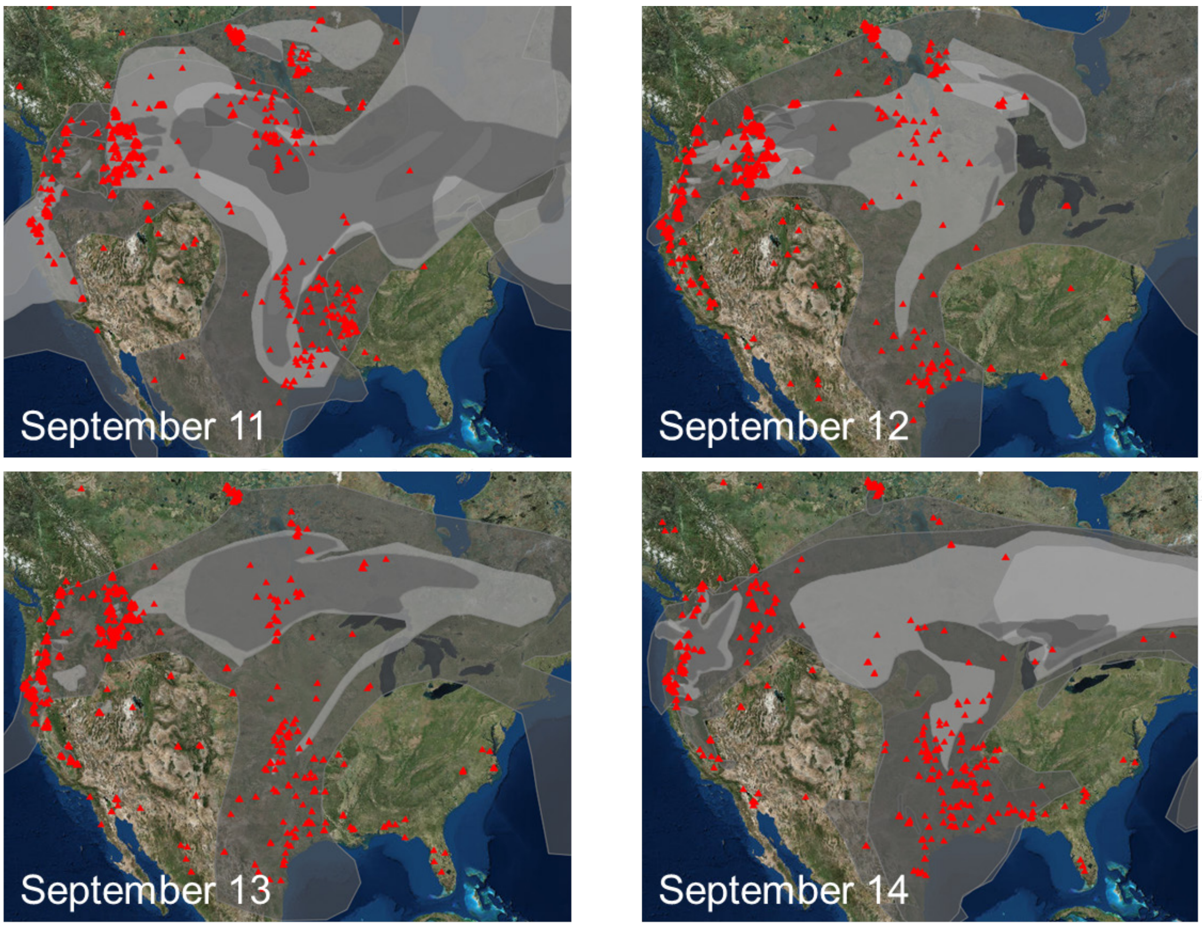

Figure 8. Daily NOAA HMS fire and smoke observations. Red triangles indicate a fire detected by satellite observation. Gray areas indicate the locations of smoke plumes observed in satellite imagery. Image source: EPA AirNow-Tech.

The HMS fire and smoke maps show large, active fires in the northwestern United States on the days leading up to September 14. There is also significant fire activity in Central Canada on those days. Scattered fires in Louisiana and nearby states, including Texas, Arkansas, and Oklahoma, are also apparent. In addition to the fire activity, the maps also show large smoke plumes extending across much of the northern United States and Canada. A substantial smoke plume extends southward through the central United States on each day between September 11 and 14. This plume corresponds to the elevated levels of ozone and $PM_{2.5}$ measured throughout the central United States in the days leading up to September 14.

The HMS smoke plume data for the days leading up to September 14 were obtained and combined with HYSPLIT back trajectories on high ozone concentration days to identify intersections and assess the potential for smoke impacts (Section 3.3). The following sections provide further evidence, based on HYSPLIT trajectories and satellite data, of a large smoke plume that traveled from northwestern fires across the central United States to Louisiana.

3.2.3 Visible Satellite Imagery

Visible satellite imagery from the MODIS Aqua and Terra satellites plainly show transport of smoke from fires burning in the Northwest to the central and southern United States, including Louisiana, between September 7 and September 14 (**Figures 9 through 16**). This evidence corroborates the evidence of smoke over Louisiana demonstrated by the HMS maps (Section 3.2.1). The movement of a dense smoke plume from Texas and the Gulf of Mexico to Louisiana between September 13 and 14 is particularly noteworthy. The movement of this smoke corresponds to the expansion of elevated ozone and $PM_{2.5}$ AQI values in Louisiana noted above. In addition, the transport of smoke northeastward from Texas and the Gulf of Mexico is consistent with transport patterns seen in the HYSPLIT trajectory analysis presented in Section 3.3 and the satellite measurements of smoke-associated species presented in Section 3.4.

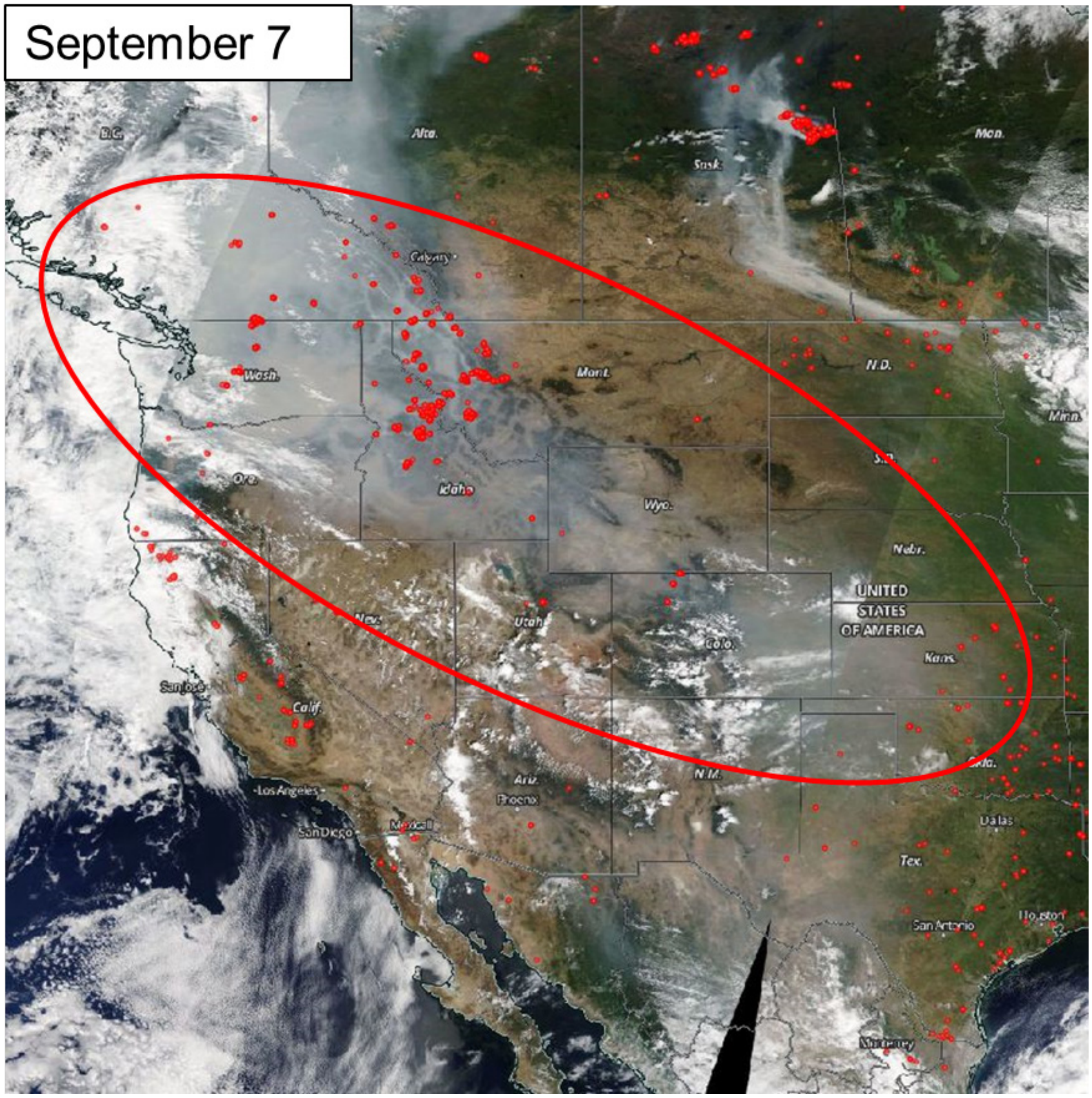

Figure 9. MODIS Terra true color satellite imagery from September 7, 2017, showing clear evidence of a dense smoke plume over Washington, northern Oregon, British Columbia, Idaho, and Montana. The visible smoke extends eastward at least as far as Kansas. Image source: NASA Worldview.

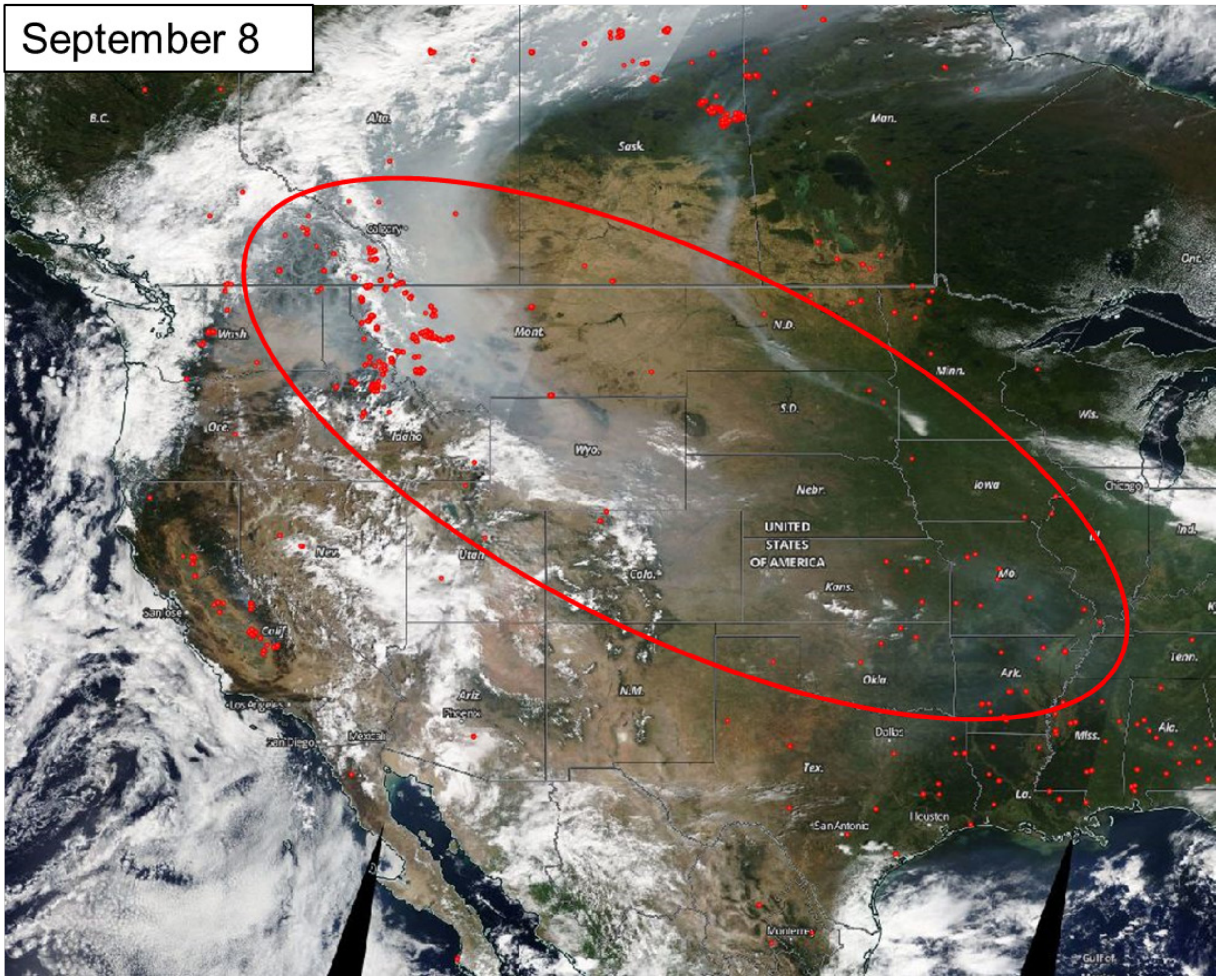

Figure 10. MODIS Terra true color satellite imagery from September 8, 2017, showing clear evidence of a dense smoke plume that extends as far east as Missouri. Image source: NASA Worldview.

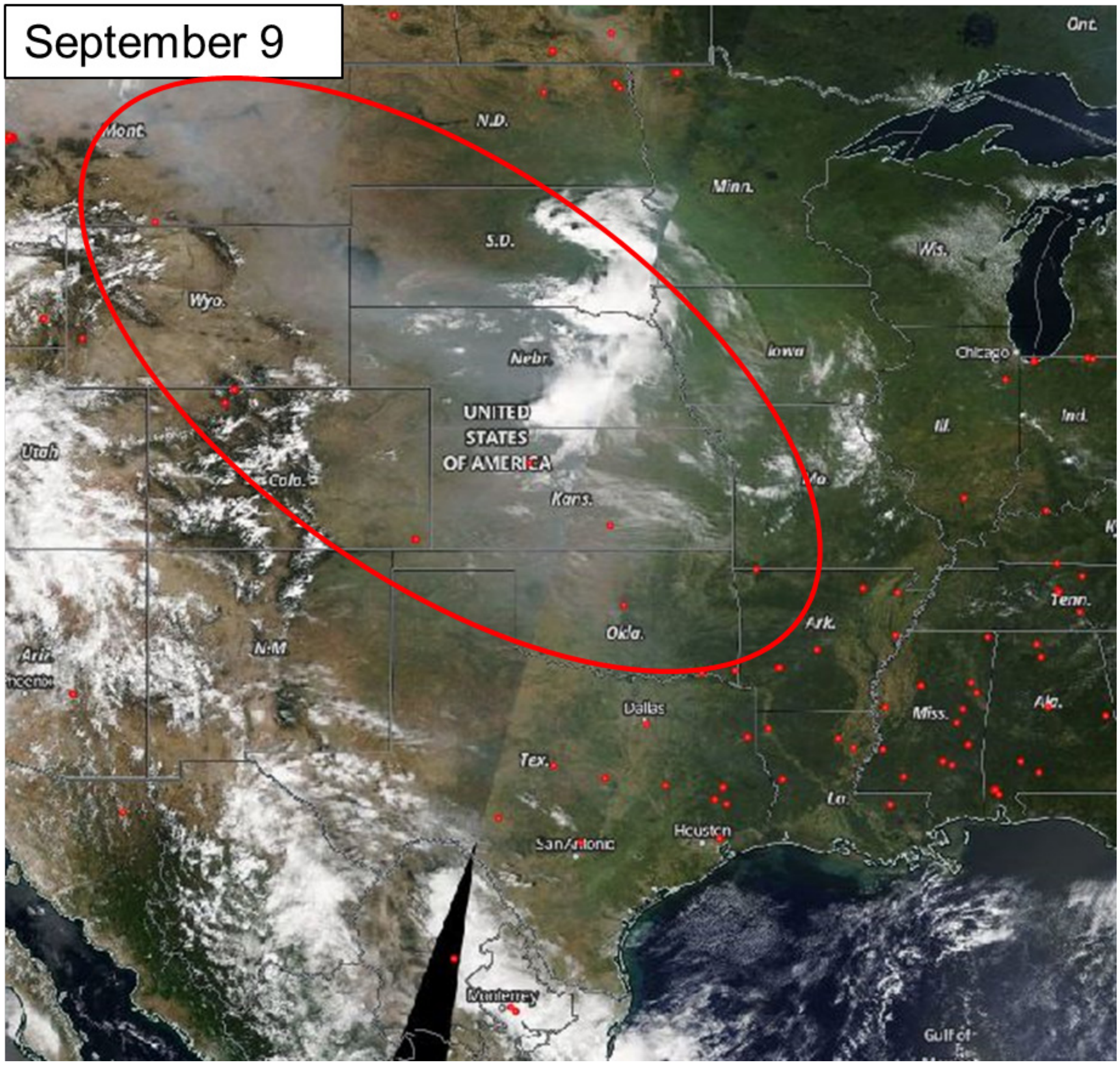

Figure 11. MODIS Terra true color satellite imagery from September 9, 2017, showing clear evidence of a dense smoke plume over the central United States. Image source: NASA Worldview.

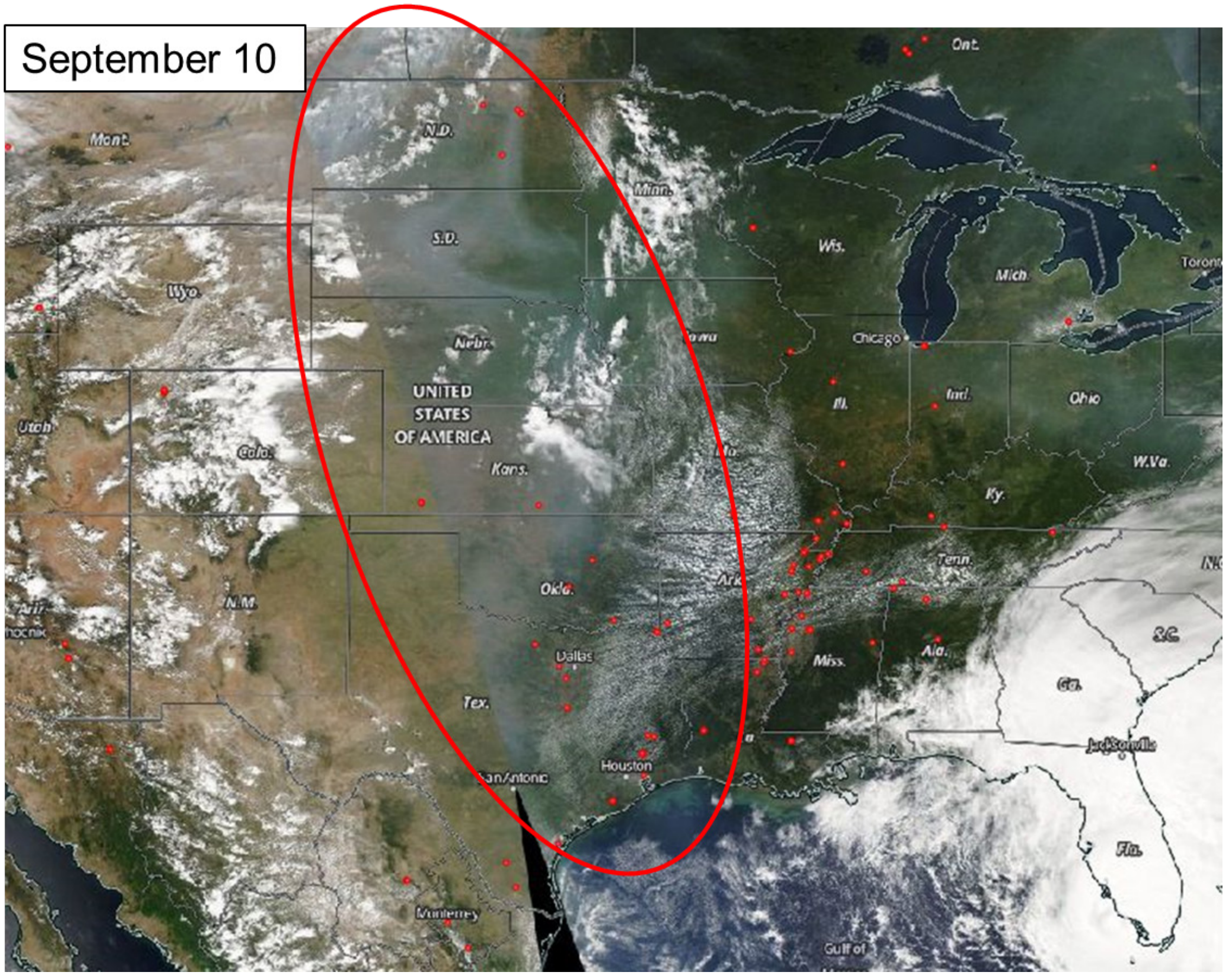

Figure 12. MODIS Aqua true color satellite imagery from September 10, 2017, showing clear evidence of a dense smoke plume that extends north to south over the central United States from North Dakota to Texas. Hurricane Irma is evident in the bottom right corner of the image. The hurricane likely contributed to the north-south distribution of the smoke plume. Image source: NASA Worldview.

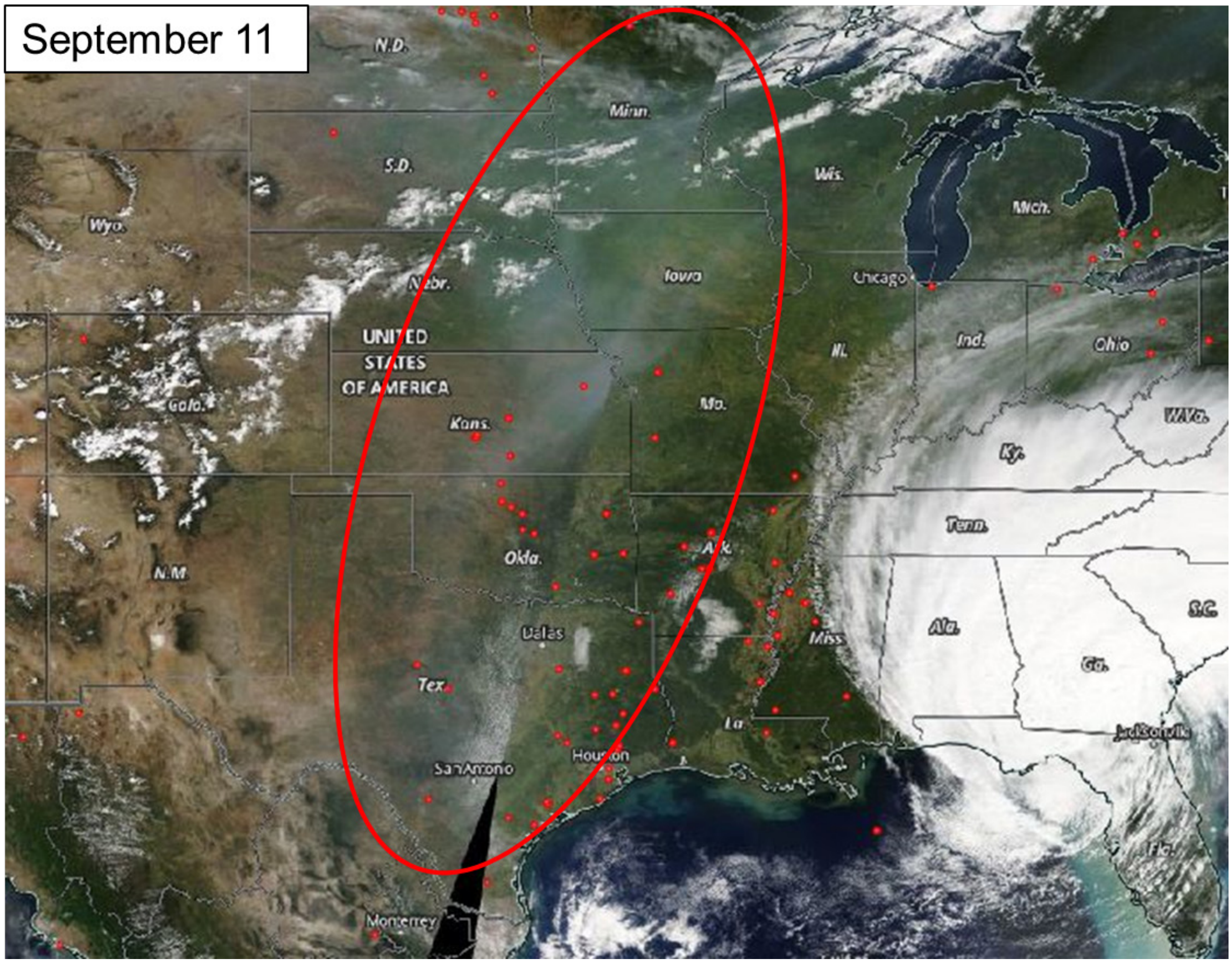

Figure 13. MODIS Terra true color satellite imagery from September 11, 2017, showing evidence of a smoke plume extending from Iowa to Texas. Hurricane Irma has moved northwest since the previous day, contributing to the alignment of the smoke north to south. Image source: NASA Worldview.

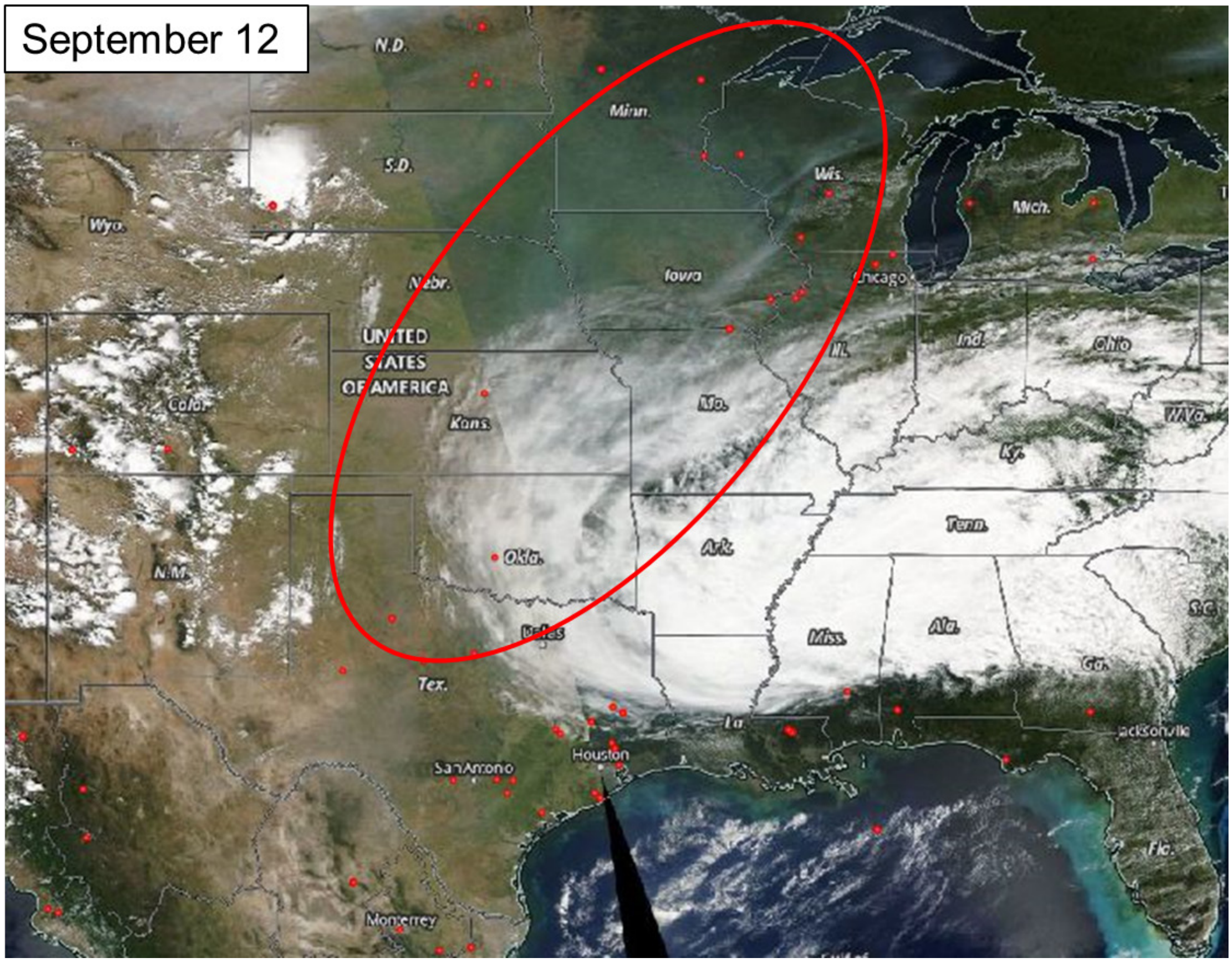

Figure 14. MODIS Aqua true color satellite imagery from September 12, 2017. Smoke is visible in northern Iowa, Nebraska, and Minnesota. Smoke farther south around Kansas and Oklahoma has been obscured by cloud cover associated with Hurricane Irma. Image source: NASA Worldview.

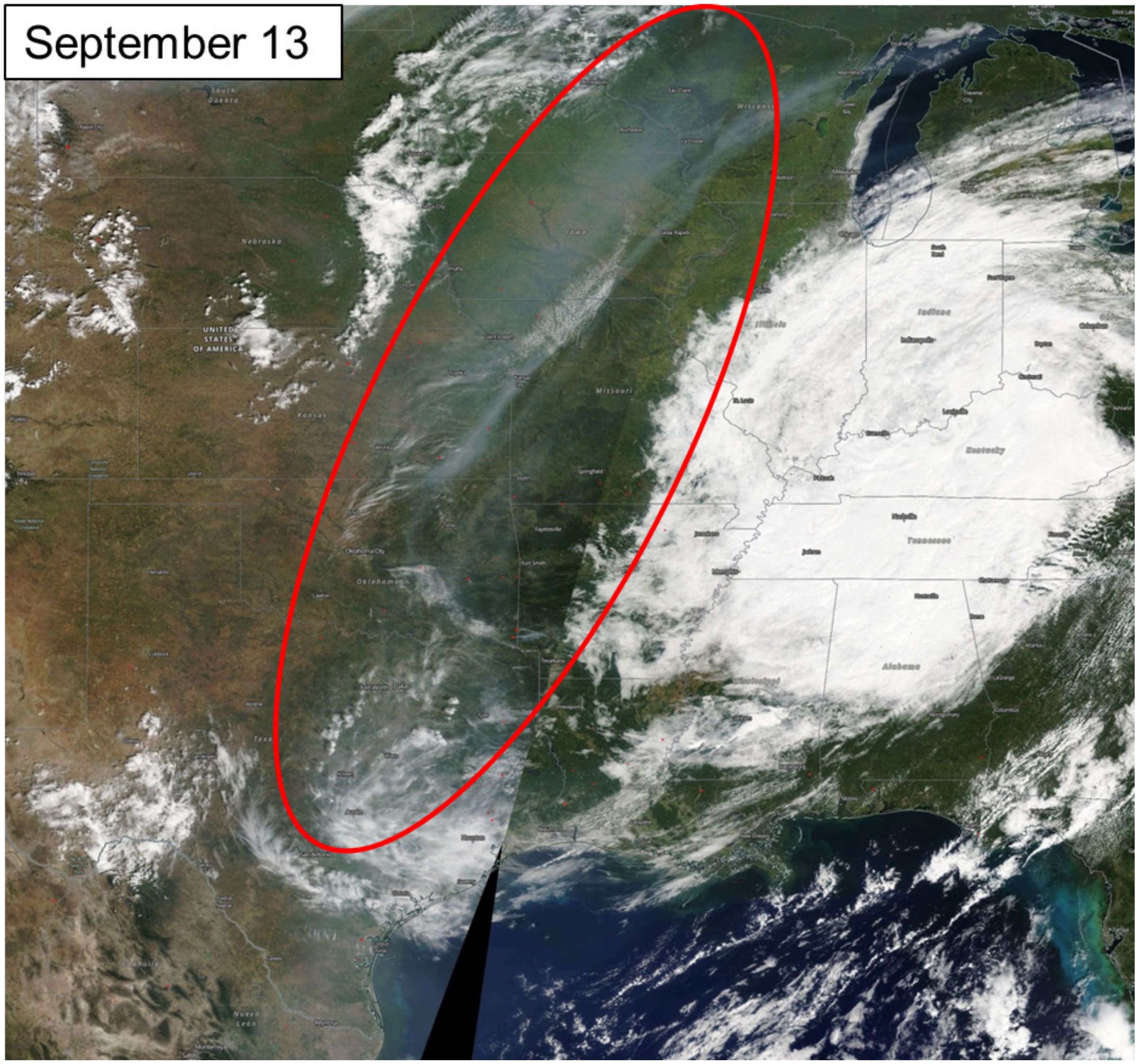

Figure 15. MODIS Terra true color satellite imagery from September 13, 2017, showing evidence of a smoke plume that extends from Texas to Iowa. Smoke that was obscured on the previous day has become apparent as Hurricane Irma moves eastward. Image source: NASA Worldview.

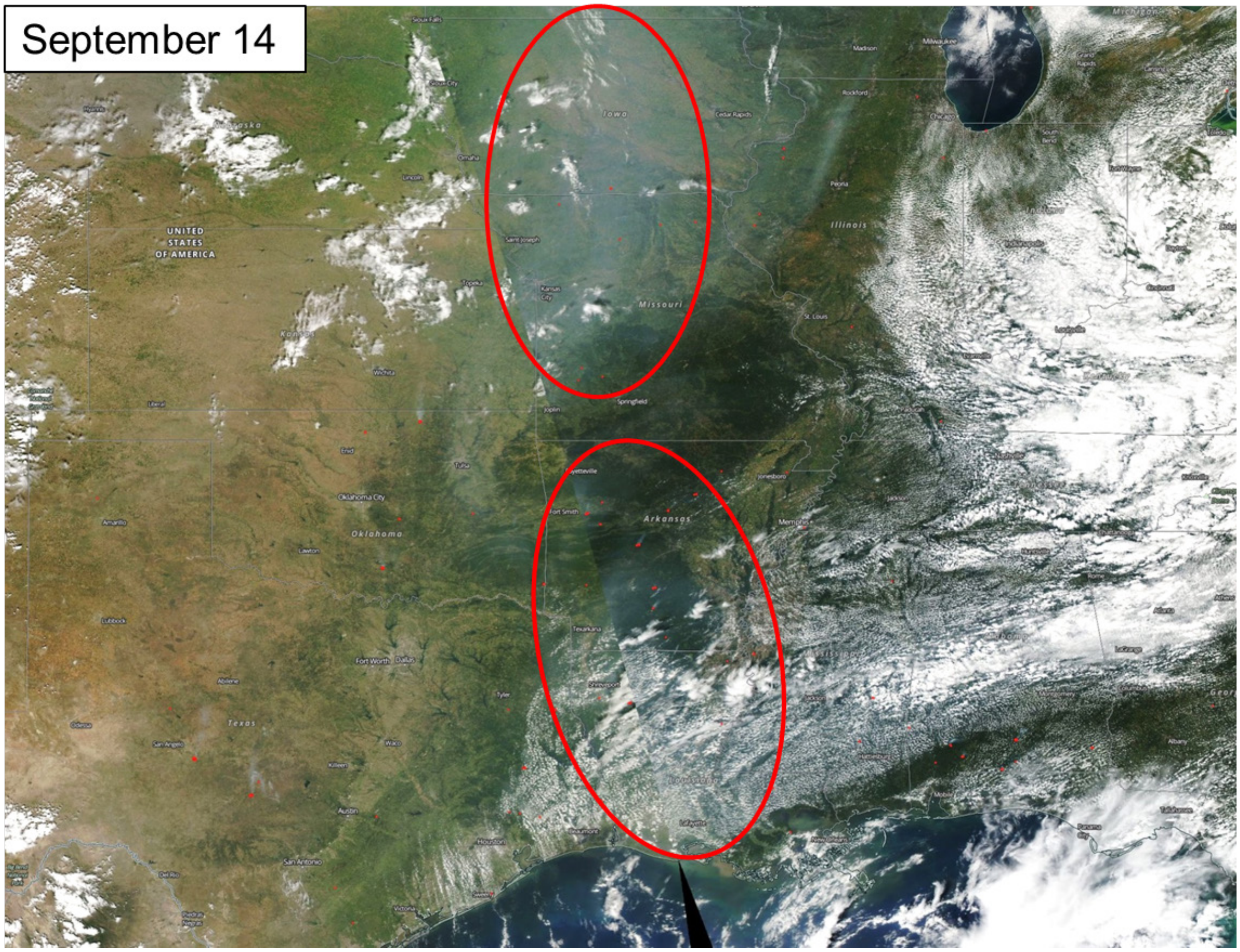

Figure 16. MODIS Aqua true color satellite imagery from September 14, 2017, showing that the smoke plume observed on previous days has moved into a north-south line over Iowa, Missouri, Arkansas, and Louisiana. Image source: NASA Worldview.

3.3 HYSPLIT Trajectories

HYSPLIT trajectories were run to demonstrate the transport of air parcels to Baton Rouge from upwind areas, and to show transport of smoke-containing air parcels from wildfires toward the affected monitor. These trajectories show that air was transported from wildfires in Idaho and Montana to Texas in the days prior to the event and that air from Texas was transported across the Gulf of Mexico to Louisiana between September 12 and 14. Combined with satellite observations described in Sections 3.2 and 3.4, the trajectories demonstrate that smoke was transported from wildfires in the northwestern United States to Baton Rouge.

NOAA's HYSPLIT model was used for the trajectory modeling (http://ready.arl.noaa.gov/HYSPLIT.php). HYSPLIT is a commonly used model that calculates the path of a single air parcel from a specific location and height above the ground over a period of time; this path is the modeled trajectory.

HYSPLIT trajectories can be used as evidence that fire emissions were transported to an air quality monitor; trajectory analysis is one option for meeting the Tier 1 requirement and is required under Tier 3.

The model options used for this study are summarized in **Table 6**. The 12-km resolution meteorological data from the North American Mesoscale Forecast System (NAM) were used (http://www.emc.ncep.noaa.gov/NAM). These data are high-spatial-resolution, are readily available for HYSPLIT modeling over the desired lengths of time, and are expected to capture fine-scale meteorological variability. Backward trajectory start times were selected to coincide with peak 8-hr ozone concentrations on September 14, 2017. As suggested in the EPA's exceptional event guidance, a backward trajectory length of 72 hours was selected to assess whether smoke from the current day or from the previous two days may have been transported over a long distance to the monitoring sites. Trajectories were initiated at 50 m, 500 m, and 1,000 m above ground level to capture transport throughout the mixed boundary layer, as ozone precursors may be transported aloft and influence concentrations at the surface through vertical mixing. Three backward trajectory approaches available in the HYSPLIT model were used in this analysis, including site-specific trajectories, trajectory matrix, and trajectory frequency. Site-specific trajectories are single trajectories run to arrive at a given site, trajectory matrices provide trajectories that arrive at a grid of points covering a specified area, and trajectory frequency analyses show the frequency with which multiple trajectories initiated over multiple hours pass over each location on a map. Together, these trajectory analyses indicate the transport patterns in Baton Rouge on September 14.

Based on trajectories and satellite data, the location at which back trajectories ended was used to initiate additional back trajectories to show long-range air transport over multiple days. Additionally, a forward trajectory matrix was run for fires in the northwestern United State to show transport of air from these fires in the direction of Louisiana. Finally, back trajectories were run for the Dutchtown monitor using higher resolution meteorological data to demonstrate vertical air transport (Section 3.5.2).

Table 6. HYSPLIT trajectory model options used in this study.

	Backward Trajectory Analysis – Site-Specific	Backward Trajectory Analysis – Matrix	Backward Trajectory Analysis – Frequency	Forward Trajectory Analysis – Matrix	Backward Trajectory Analysis – High Resolution (Section 3.5)
Meteorology	12-km NAM	12-km NAM	12-km NAM	12-km NAM	3-km HRRR[a]
Time Period	September 12-14, 2017	September 14, 2017	September 14, 2017	September 8-13, 2017	September 12-14, 2017
Starting Location	Capitol, monitoring site (Site ID: 220330009)	Evenly spaced grid covering Baton Rouge	Capitol, monitoring site (Site ID: 220330009)	Evenly spaced grid covering fires in Idaho and Montana	Dutchtown monitoring site
Trajectory Time Length	72 hours	72 hours	72 hours	120 hours	24 hours
Starting Heights (AGL)	50 m, 500 m, 1,000 m	50 m, 500 m, 1,000 m	50 m, 500 m, 1,000 m	1,000 m	50 m
Starting Times	1600 UTC	1600 UTC	1600 UTC	1600 UTC	Every 3 hours between 0200 UTC Sept. 12 and 2300 UTC Sept. 14
Vertical Motion Method	Model vertical velocity	Model vertical velocity	Model vertical velocity	Model vertical velocity	Model vertical velocity
Top of Model	10,000 m AGL	10,000 m AGL	10,000 m AGL	10,000 m AGL	10,000 m AGL

[a] NOAA's High-Resolution Rapid Refresh model.

Site-specific backward trajectories were calculated from the downtown Baton Rouge Capitol monitoring site on September 14, 2017, at (10:00 a.m. CST/4:00 p.m. UTC, when ozone concentrations were the highest of the day. **Figure 17** shows backward trajectories, along with measured ozone (8-hr begin time average) at other monitoring sites and HMS fire detect locations on September 14, 2017. As shown in Figure 17, each trajectory height follows a similar backward path from Baton Rouge and travels over or near several active fire locations. HMS smoke plume data are overlaid and displayed in **Figures 18 and 19**. As shown in Figure 18, smoke is identified over much of the map on September 14, 2017. Additionally, elevated ozone concentrations are evident at other sites in the area where smoke was present. Previous-day trajectory plots shown in Figure 19 show similar smoke plume coverage over the area; however, backward trajectories originating from Baton Rouge on those days do not intersect with the plumes.

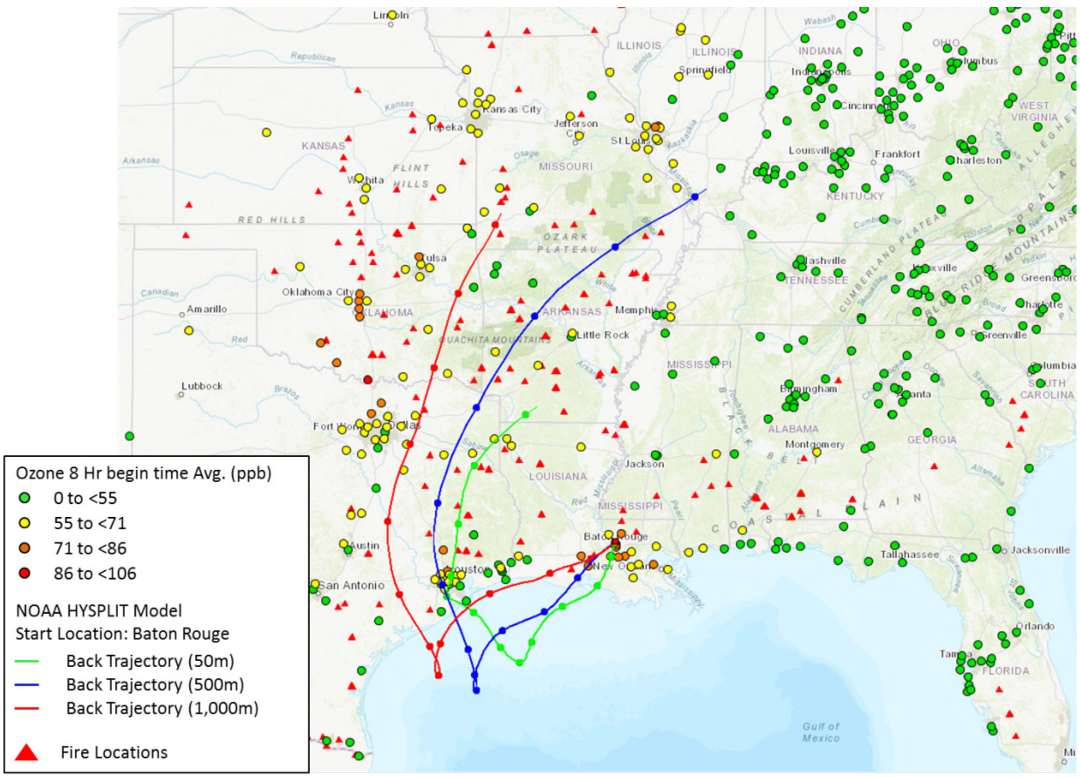

Figure 17. Backward trajectories from Baton Rouge on September 14, 2017.

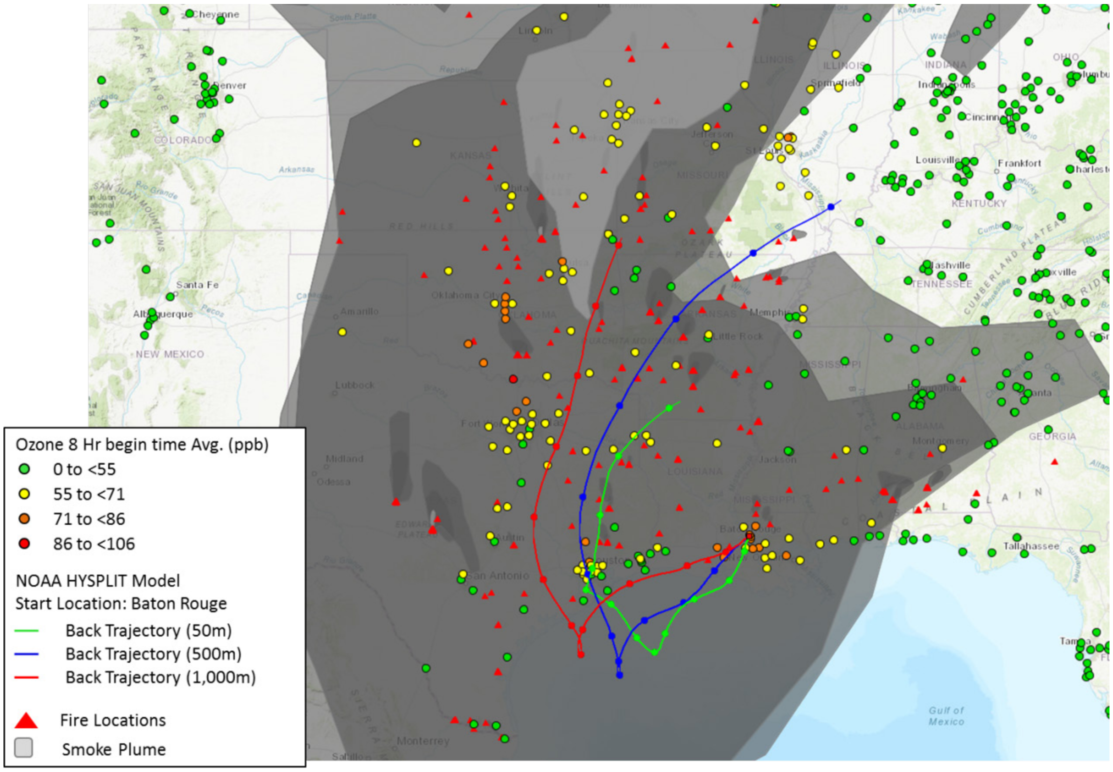

Figure 18. Backward trajectories from Baton Rouge on September 14, 2017, overlaid with HMS fire detect and location smoke plume data.

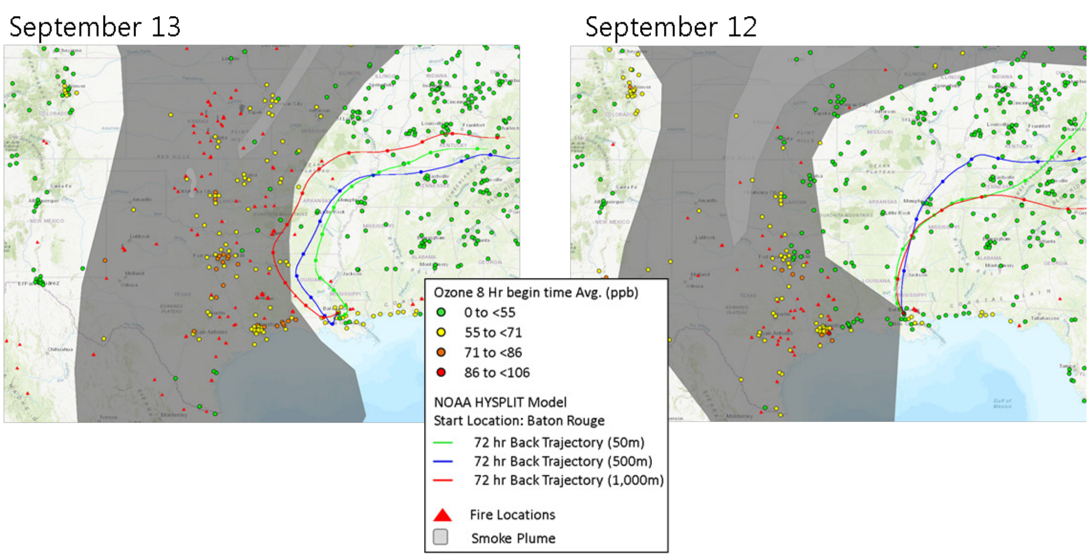

Figure 19. Backward trajectories from Baton Rouge on September 13 and 12, 2017, overlaid with HMS fire detect locations and smoke plumes.

The second trajectory approach used in this analysis was HYSPLIT trajectory matrix. In the trajectory matrix option, trajectories are run in an evenly spaced grid of source locations. The objective of this analysis was to identify variations in meteorological patterns of transported air to the greater Baton Rouge area. Figure 20 shows a 72-hour backward trajectory matrix with source locations encompassing the greater Baton Rouge area. The backward trajectories were initiated on September 14, 2017 (10:00 a.m. CST/4:00 p.m. UTC), when ozone concentrations were the highest of the day, at a starting height of 50 m AGL. As shown in Figure 20, transported air intersecting the greater Baton Rouge area on September 14, 2017, follows a consistent pattern. Much like the trajectories depicted in Figure 17, transported air traveled from Western Texas, over the Houston area, over the Gulf of Mexico, and progressed back to the northeast to intersect Baton Rouge at 50 m AGL.

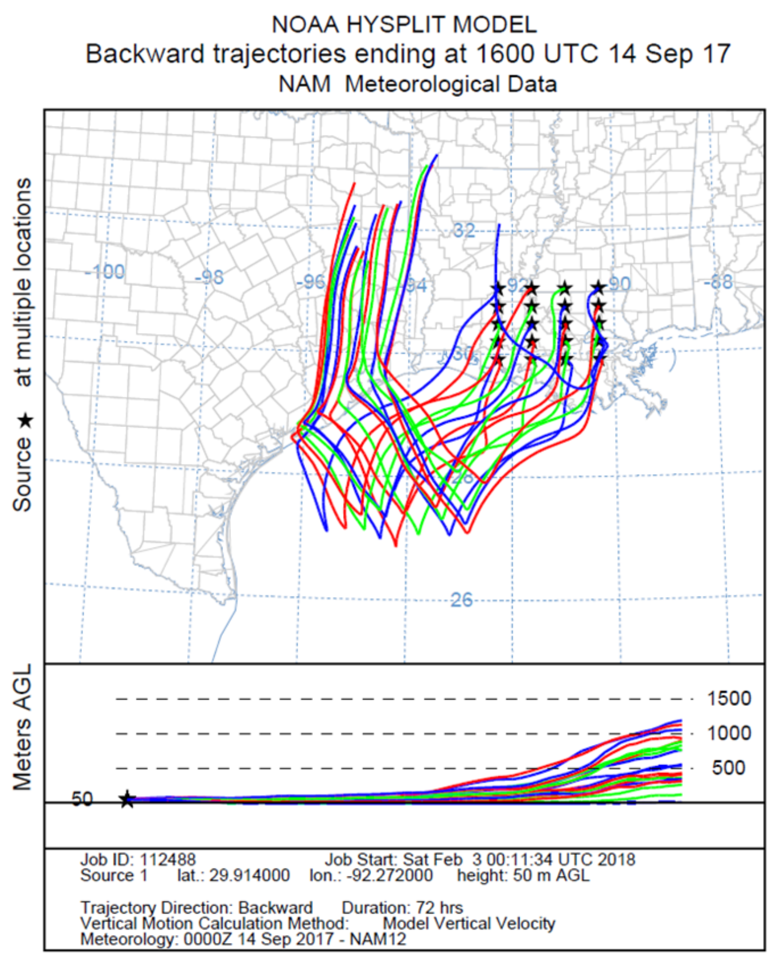

Figure 20. Backward trajectory matrix for the greater Baton Rouge area on September 14, 2017.

The third trajectory approach used in this analysis was HYSPLIT trajectory frequency. The trajectory frequency option starts a trajectory from a single location and height every three hours. Using a continuous 0.25 degree grid, the frequency of trajectories passing through each grid cell is totaled and then normalized by the total number of trajectories. Figure 21 shows a 72-hour backward trajectory frequency plot, using the Capitol monitoring site as the starting location and 50 m AGL as the starting height. The trajectory frequency plot provides similar results as the previous two approaches; transported air impacting Baton Rouge on September 14, 2017, is predominately coming from Western Texas and passing over the Houston area. Backward trajectory frequency plots with starting heights at 500 and 1,000 m AGL show transported air extending to Arkansas and Southern Missouri, as shown in Figure 22.

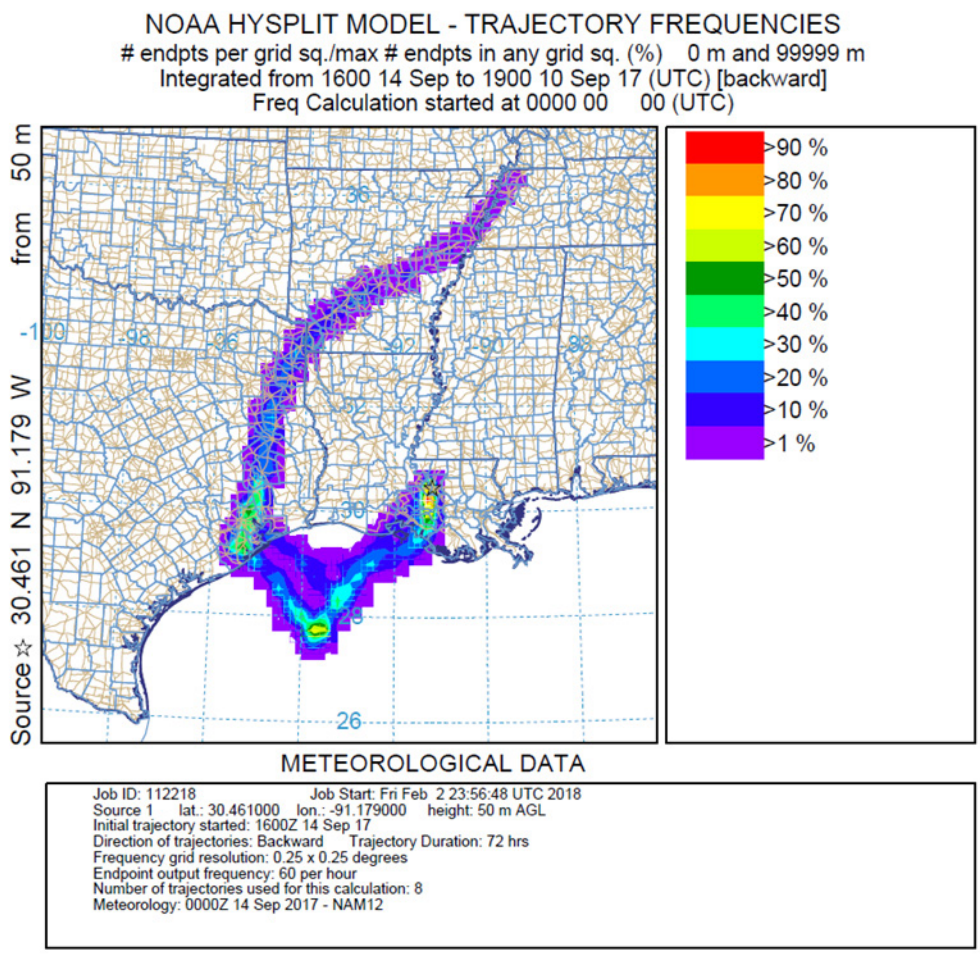

Figure 21. Backward trajectory frequency plot for the greater Baton Rouge area originating on September 14, 2017.

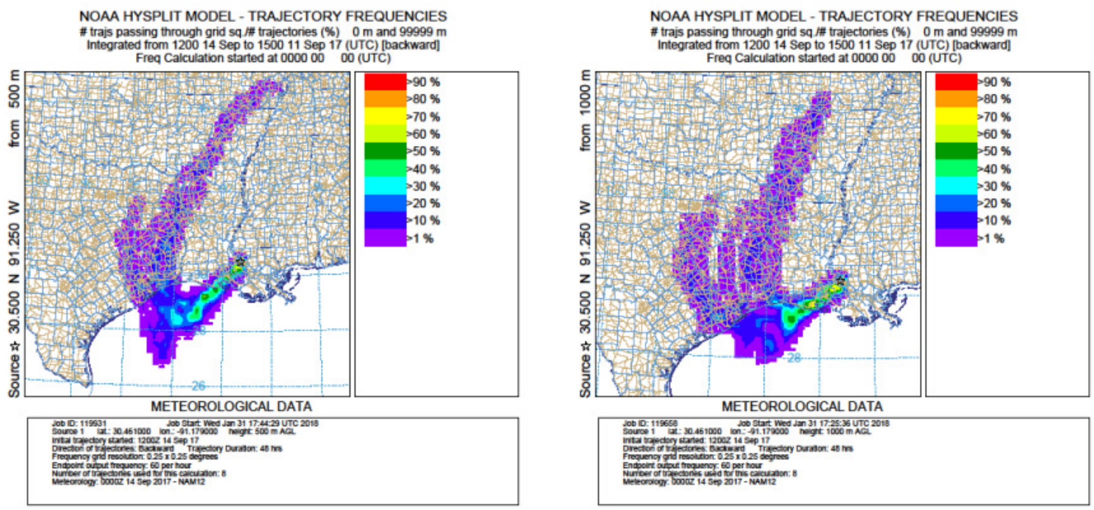

Figure 22. Backward trajectory frequency plots for the greater Baton Rouge area originating on September 14, 2017, at starting heights of 500 and 1,000 m AGL.

Forward trajectories were run from fires in the northwestern United States starting at 1600 UTC on September 8 (**Figure 23**). These trajectories show that smoke was transported from fires in the Northwest in two major transport patterns. Some air parcels traveled northeastward from the fires, while others traveled southeastward to Oklahoma and Texas. These forward trajectories, combined with the back trajectories showing smoke transport from Texas to Louisiana, further support the transport of smoke from northwestern fires to Louisiana.

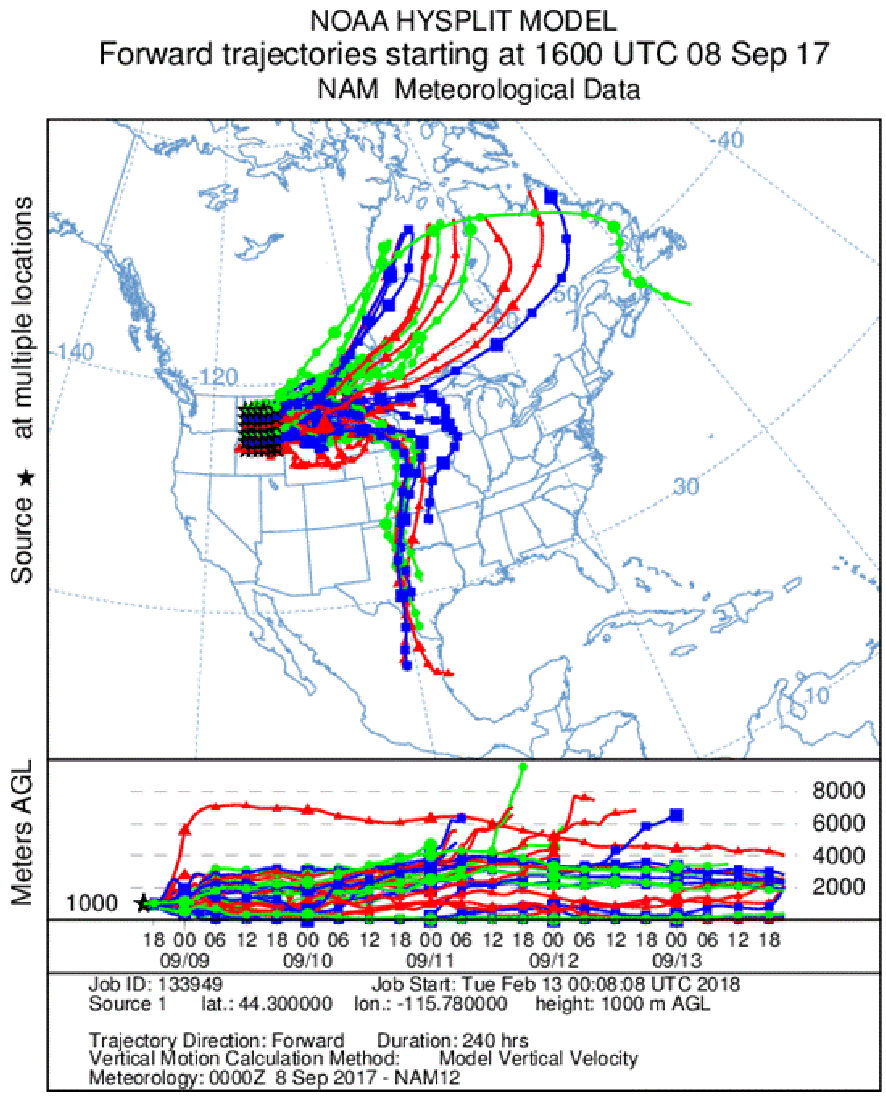

Figure 23. Forward trajectory plots for trajectories originating at 1600 UTC on September 8, 2017, at starting height of 1,000 m AGL.

3.4 Satellite NO_x, AOD, and CO

Satellite retrievals of pollutants associated with wildfire smoke, such as AOD, CO, and NO_x, can provide evidence that smoke was present at the monitoring site. We examined maps of AOD from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard the Aqua and Terra satellites, CO retrievals from the Atmospheric Infrared Sounder (AIRS) instrument onboard the Aqua satellite, and NO_2 retrievals from the Ozone Monitoring Instrument (OMI). These maps provide evidence to support the transport of smoke from fires in the northwestern United States to Louisiana, as already demonstrated with visual imagery and trajectories.

MODIS AOD measurements indicate the concentration of light-absorbing aerosols, including those emitted by wildfires, in the total atmospheric column. Between September 9 and September 14, AOD measurements show the movement of a dense plume of aerosols originating near fires in the Northwest (**Figure 24**). This plume moves to the central United States between September 9 and September 11. The plume is then transported southward to Texas by weather patterns associated with Hurricane Irma, producing a north-south line of elevated AOD between Texas and Iowa on September 13. On September 14, the aerosol plume moves eastward from Texas to Louisiana. Despite partial obstruction by cloud cover, MODIS Aqua AOD retrievals indicate elevated aerosols in the Baton Rouge area on September 14 (**Figure 25**).

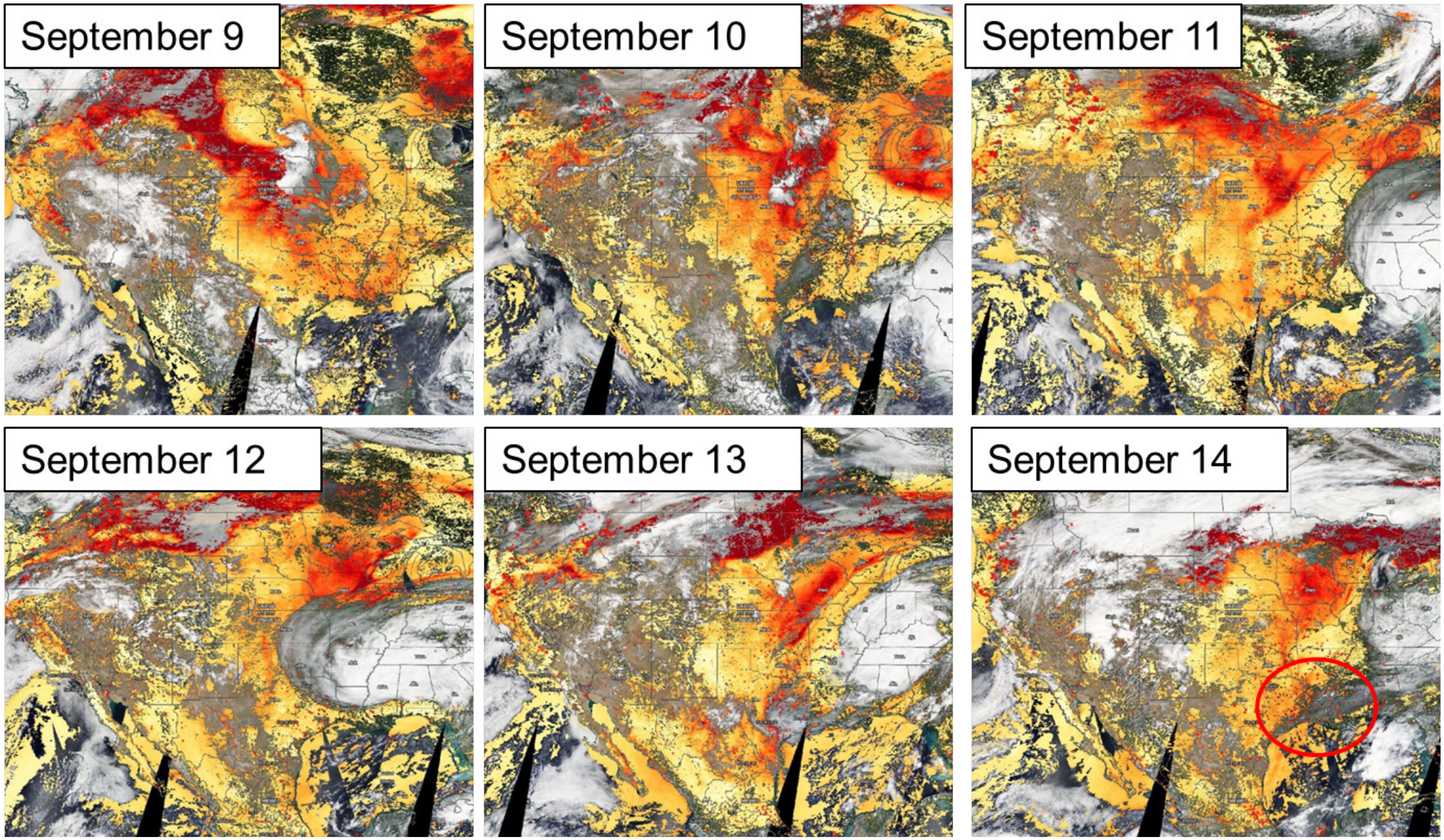

Figure 24. MODIS (Aqua/Terra) aerosol optical depth retrievals from the "Dark Target" algorithm at 3 km spatial resolution for September 9 through September 14, 2017. AOD indicates the concentration of aerosols in the total atmospheric column. Yellow indicates low AOD, while orange and red indicate increasingly higher AOD. Missing data are represented as transparent, with MODIS visible imagery from the indicated day underlying the AOD layer. Scattered aerosol retrievals and missing data due to cloud cover over Louisiana are indicated with a red circle for September 14. Image source: NASA Worldview.

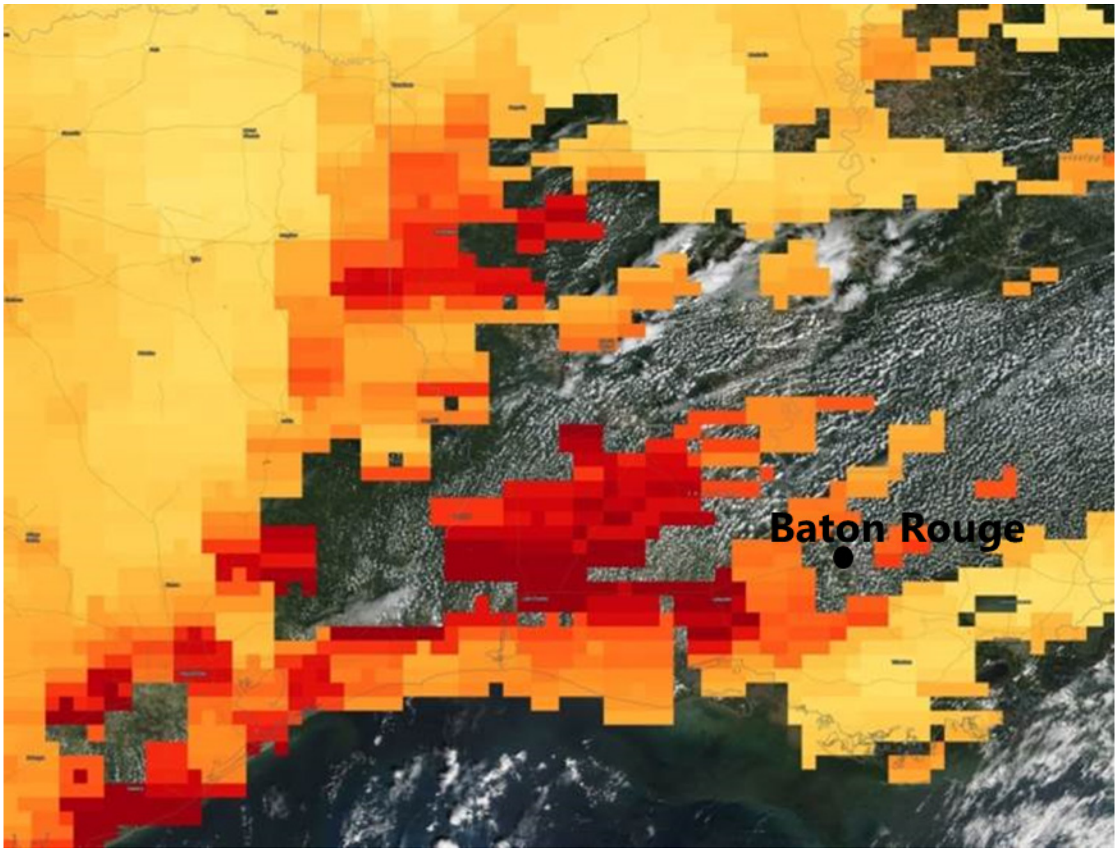

Figure 25. MODIS Aqua aerosol optical depth retrievals from the "Deep Blue" algorithm at 10 km nominal spatial resolution for September 14, 2017, over Baton Rouge. Images were acquired between approximately 12:30 p.m. and 2:15 p.m. CST. AOD indicates the concentration of aerosols in the total atmospheric column. Yellow indicates low AOD, while orange and red indicate increasingly higher AOD. Missing data are represented as transparent, with MODIS visible imagery from the indicated day underlying the AOD layer. Image source: NASA Worldview.

Carbon monoxide measurements from AIRS show the same pattern of smoke plume transport seen in the MODIS AOD data noted above. The maps show smoke transport from the northwest to the central United States between September 9 and September 11 (**Figure 26**). The north-south line of CO, indicating a smoke plume, between Texas and Iowa on September 13 is particularly clear in this imagery. By slightly after midnight on September 14, the CO plume has been transported eastward from Texas to Louisiana (**Figure 27**). Total column concentrations of CO observed over Louisiana, up to 120 ppb, on that day are about 50% higher than typical background concentrations of 70-90 ppb. These observations are much higher than those observed elsewhere in the United States on September 14. This imagery clearly indicates the presence of a smoke plume over Louisiana by the beginning of September 14.

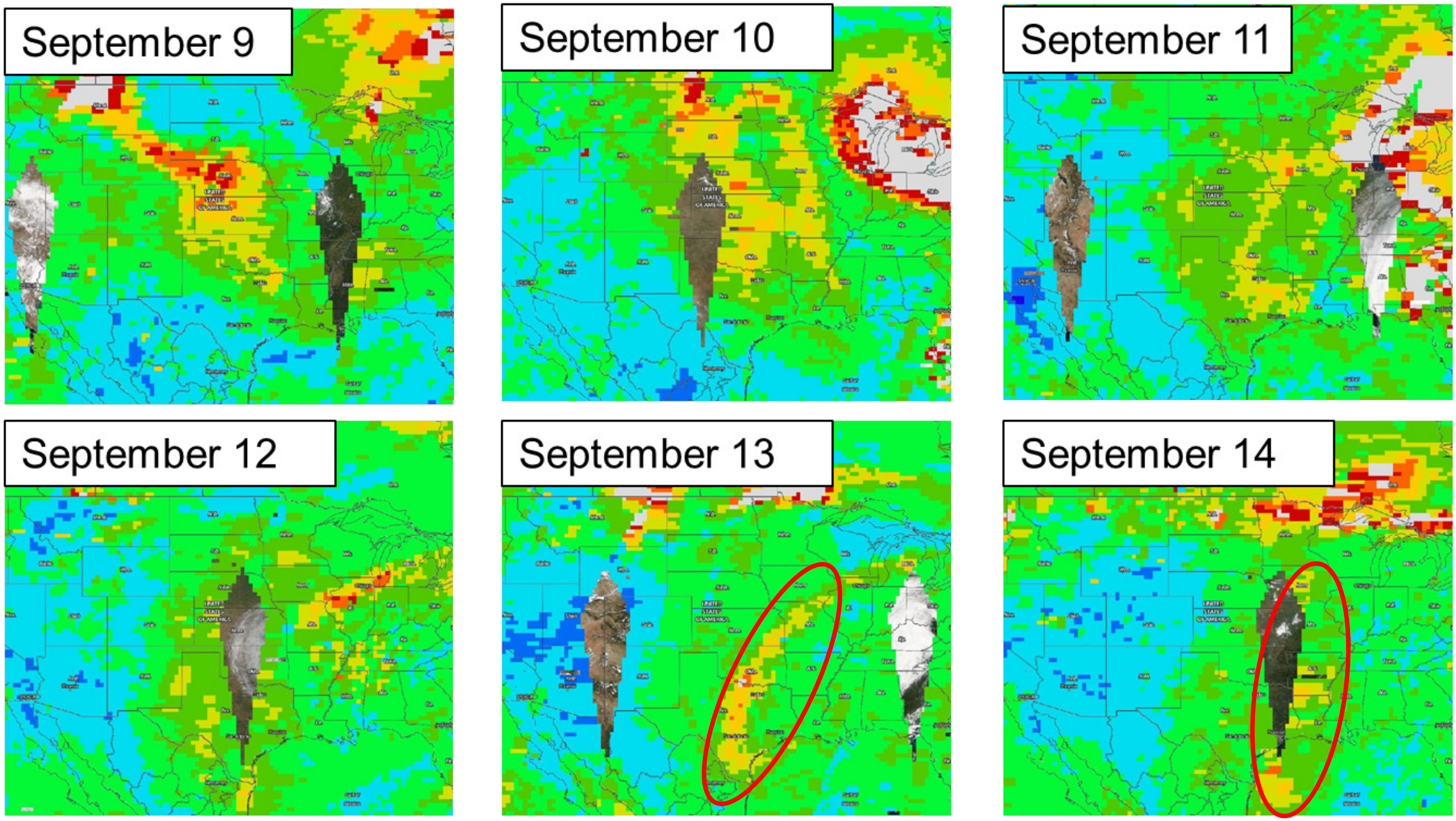

Figure 26. Atmospheric Infrared Sounder (AIRS) carbon monoxide total column retrievals combined for day and night for September 9 through September 14. Cool colors (dark blue: 60-70 ppb, blue: 70-80 ppb) indicate low CO mixing ratios, greens (light green: 80-90 ppb, dark green: 90-100 ppb) indicate moderate to high CO mixing ratios, and warm colors (yellow: 100-110 ppb, orange: 110-120 ppb, dark orange: 120-130 ppb, red: 130-140 ppb, and white: >= 140 ppb) indicate high CO mixing ratios. Plumes on September 13 and 14 are indicated with red circles. Missing data are represented as transparent, with MODIS visible imagery from the indicated day underlying the CO layer. Image source: NASA Worldview.

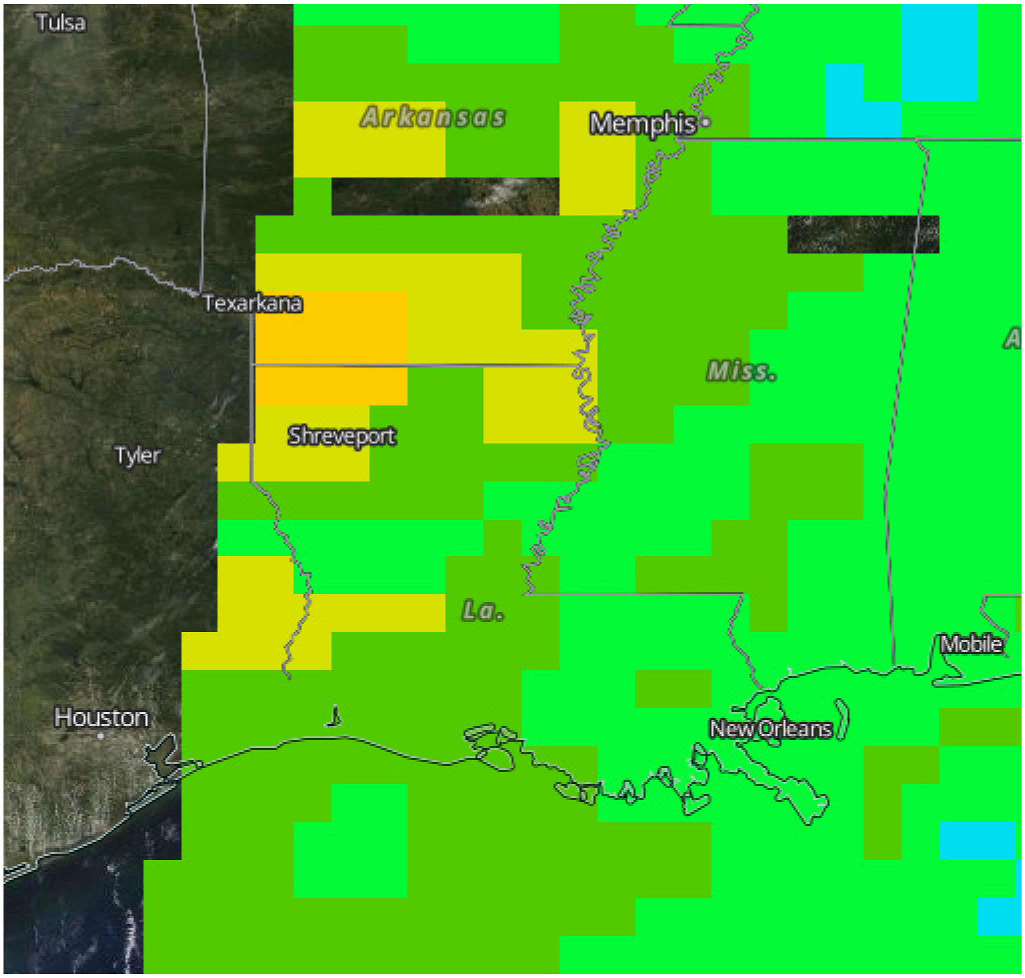

Figure 27. Atmospheric Infrared Sounder (AIRS) carbon monoxide total column nighttime retrievals at approximately 1:35 AM CST on September 14. Cool colors (dark blue: 60-70 ppb, blue: 70-80 ppb) indicate low CO mixing ratios, greens (light green: 80-90 ppb, dark green: 90-100 ppb) indicate moderate to high CO mixing ratios, and warm colors (yellow: 100-110 ppb, orange: 110-120 ppb, dark orange: 120-130 ppb, red: 130-140 ppb, and white: ≥140 ppb) indicate high CO mixing ratios. Missing data are represented as transparent, with MODIS visible imagery from September 14 underlying the CO layer. Image source: NASA Worldview.

We additionally examined OMI retrievals of tropospheric NO_2 (Figure 28). However, the retrievals likely reflect urban sources rather than NO_2 from smoke. Even over areas of dense, visible smoke and near actively burning fires, where significant smoke is present in the troposphere, the measurements show little increase in measured NO_2. Therefore, it was determined that NO_2 does not provide strong evidence for or against smoke impacts in Baton Rouge.

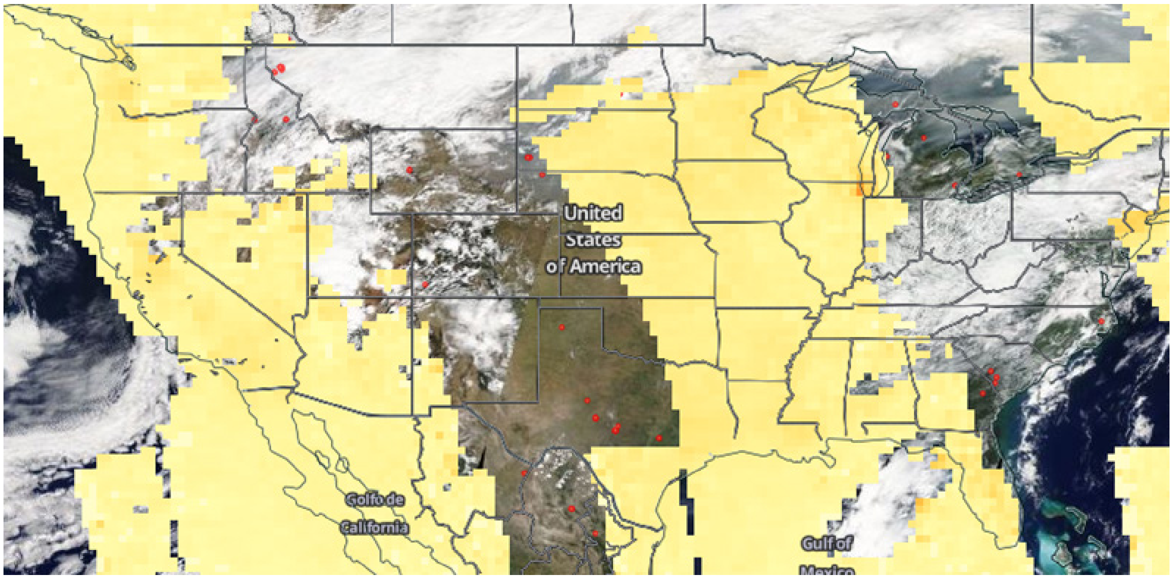

Figure 28. OMI retrievals of the tropospheric component of the total NO_2 column for September 14, 2017. Light yellow indicates low concentrations of NO_2, while darker yellow and orange indicate higher concentrations. Missing data are represented as transparent, with MODIS visible imagery from September 14 underlying the NO_2 layer. Image source: NASA Worldview.

3.5 Vertical Transport of Smoke

3.5.1 Location of Smoke in the Vertical Column

The satellite analyses and HYSPLIT trajectories provided strong evidence that smoke was present over Louisiana at the time of the event on September 14, 2017. However, the visible true color, AOD, and CO satellite data do not provide information about the vertical distribution of visible or measured smoke components. We examined satellite-retrieved aerosol vertical profiles and ceilometer mixing height measurements to determine whether the smoke plume was present at the surface on September 14. We also ran additional high-resolution HYSPLIT trajectories to determine whether transport to the surface was indicated by meteorological models.

The Cloud-Aerosol Transport System (CATS), launched in January 2015, is a Light Detection and Ranging (LIDAR) remote sensing instrument mounted on the International Space Station (ISS) that provides vertical profile measurements of atmospheric aerosols and clouds. Detected aerosols are classified into marine, marine mixture, dust, dust mixture, clean/background, polluted continental, smoke, and volcanic aerosol types.

The best CATS aerosol retrieval over Louisiana for the September 14 ozone event is available at 11:30 p.m. local time on September 13 (Figure 29). The CATS vertical profile shows that a smoke plume was present over Louisiana on the night of September 13 between the altitudes of 1,400 m and approximately 5,000 m (Figures 30 and 31).

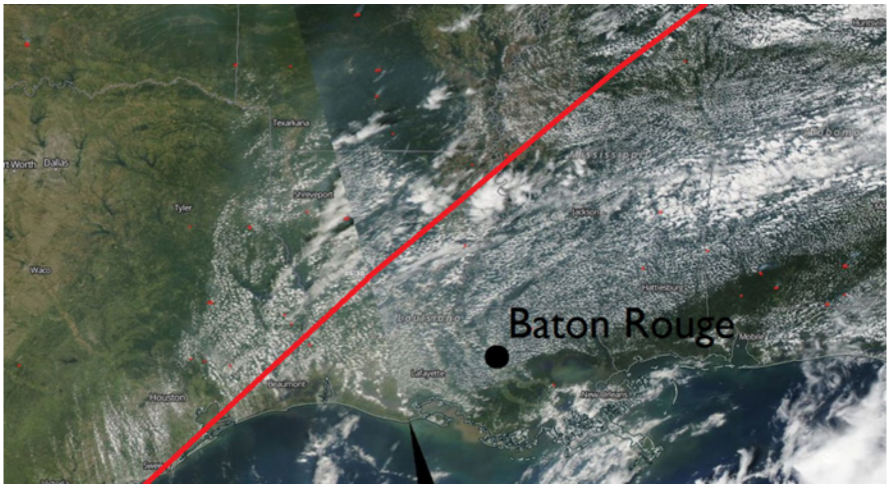

Figure 29. Location of CATS orbital track over Louisiana at approximately 11:30 p.m. CST on September 13, 2017. The center line of the instrument passes about 115 miles northwest of Baton Rouge. Image source: NASA Worldview.

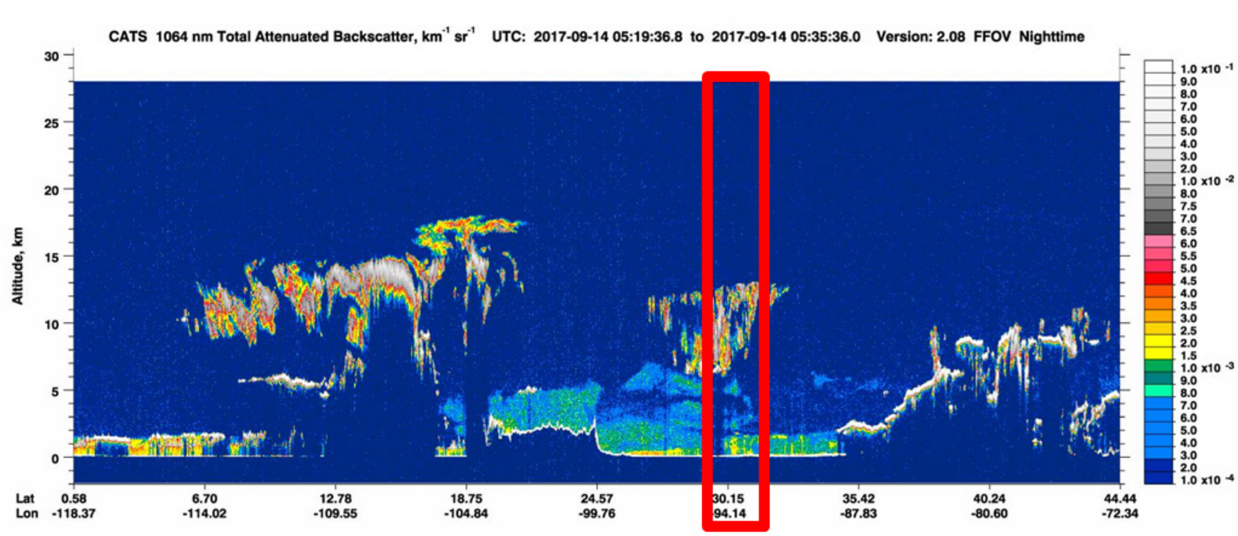

Figure 30. CATS aerosol total attenuated backscatter vertical profile at 1064 nm, collected on September 13, 2017, between 11:18 and 11:33 p.m. over the northern hemisphere. The approximate latitude at which the instrument passed over Louisiana is indicated with a red box. Image source: https://cats.gsfc.nasa.gov.

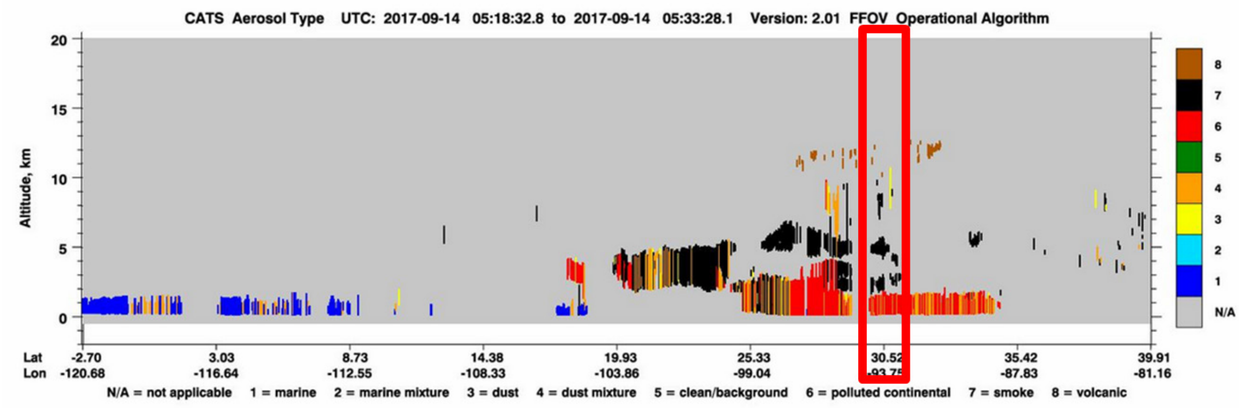

Figure 31. CATS aerosol type vertical profile collected on September 13, 2017, between 11:18 and 11:33 p.m. over the northern hemisphere. The approximate latitude at which the instrument passed over Louisiana is indicated with a red box. Image source: https://cats.gsfc.nasa.gov.

3.5.2 Vertical Mixing

On the day of the event, smoke was present over Louisiana at an altitude of 1,400 m and above. The mesoscale and local meteorological conditions on September 13 provide evidence for vertical mixing of smoke from aloft to the surface in Louisiana. As discussed in further detail in Appendix D, the regional upper-level weather pattern observed on September 13 was dominated by a trough of low pressure (associated with the remnants of Hurricane Irma) over the southeastern United States. Coinciding with this upper-level trough, a band of positive absolute vorticity stretched from the center of an upper-level low pressure system over Indiana and Kentucky across western Tennessee, through northern Alabama and Mississippi, and into Louisiana (indicated by the green, yellow, and orange shading in Figure 32). Upper-level vorticity enhances vertical mixing, allowing for aloft smoke to be mixed vertically toward the surface

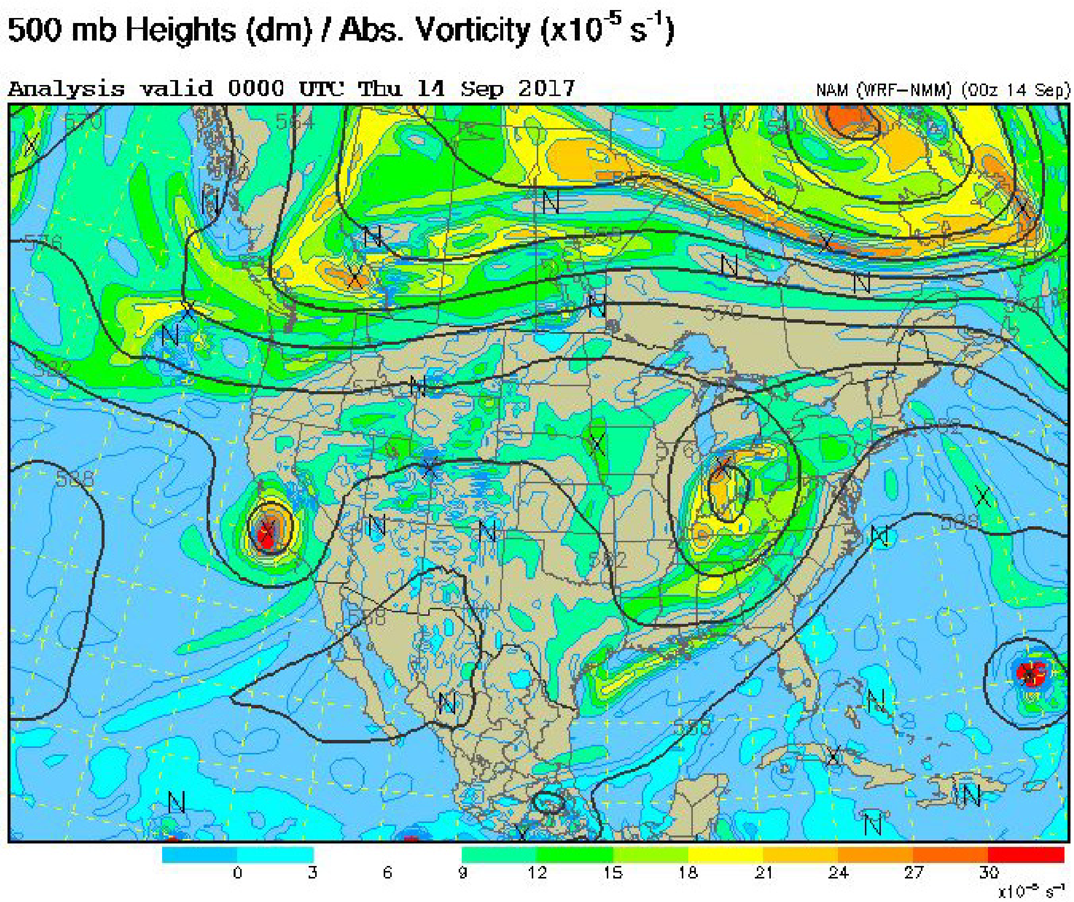

Figure 32. Analysis of 500-mb heights and absolute vorticity on the afternoon of September 13, 2017. Source: http://www2.mmm.ucar.edu/imagearchive/.

Local observations of mixing heights in the Baton Rouge area on September 13 and 14 also suggest that smoke mixed into the lower levels of the atmosphere. Ceilometer data from the Capitol site indicate mixing heights on September 13 and September 14 in excess of 1,700 m for several hours (**Figure 33**). As already noted, CATS detected a smoke plume over the area down to a height of 1,400 m. Because the layer of air below the mixing height is generally well mixed to the surface, this observation provides strong evidence for the existence of smoke in the lower levels of the atmosphere over Baton Rouge on the afternoon of September 13 and on September 14. Satellite data show that the majority of the smoke plume did not arrive over Baton Rouge until September 14. Therefore, although mixing of the smoke plume to the surface was likely to occur on both days, smoke impacts were observed in Baton Rouge primarily on September 14, as smoke at the surface and aloft was transported northeastward from the Gulf to Baton Rouge.

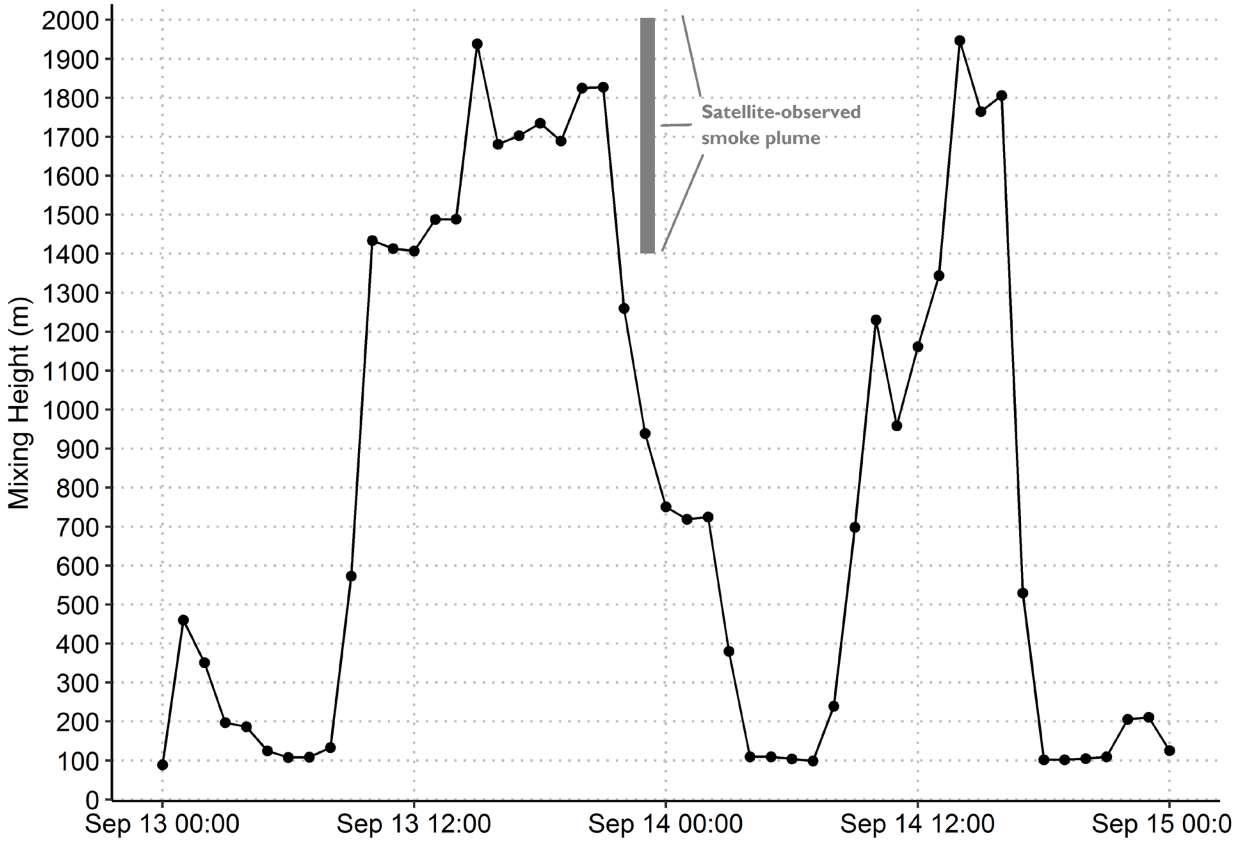

Figure 33. Mixing height in meters measured at the Capitol site using an optical scattering ceilometer on September 13 and 14, 2017. The vertical mixing height measured at each hour is shown with black points. The timing and vertical height of the observed smoke plume are also shown..

In addition to the ceilometer-based measurements of mixing heights, vertical temperature profiles can be used to estimate mixing heights. The vertical temperature profile at Lake Charles on the morning of September 14 (Figure 34) showed a strong temperature inversion (temperature increasing with height) at the same level that the smoke plume was detected by CATS (i.e., approximately 1,500 m). The vertical temperature profile observed on the afternoon of September 14 indicated a mixing height up to at least this height (Figure 35), consistent with the ceilometer mixing heights. This further supports mixing of the smoke plume to the surface.

Downward mixing and transport of air is also demonstrated by HYSPLIT trajectories run using high-resolution meteorology for the Dutchtown site (Figure 36). Trajectories arriving at the monitor site on September 14 show evidence of downward transport from elevations of up to 1,500 m, where a smoke plume had been observed the previous night.

The CATS vertical profile of aerosols over Louisiana in the evening of September 13, the ceilometer data, the vertical temperature profile, and the HYSPLIT trajectories suggest the existence of smoke within the mixed layer on the evening of September 13 and September 14 and support mixing of smoke to the surface on at Baton Rouge on September 14.

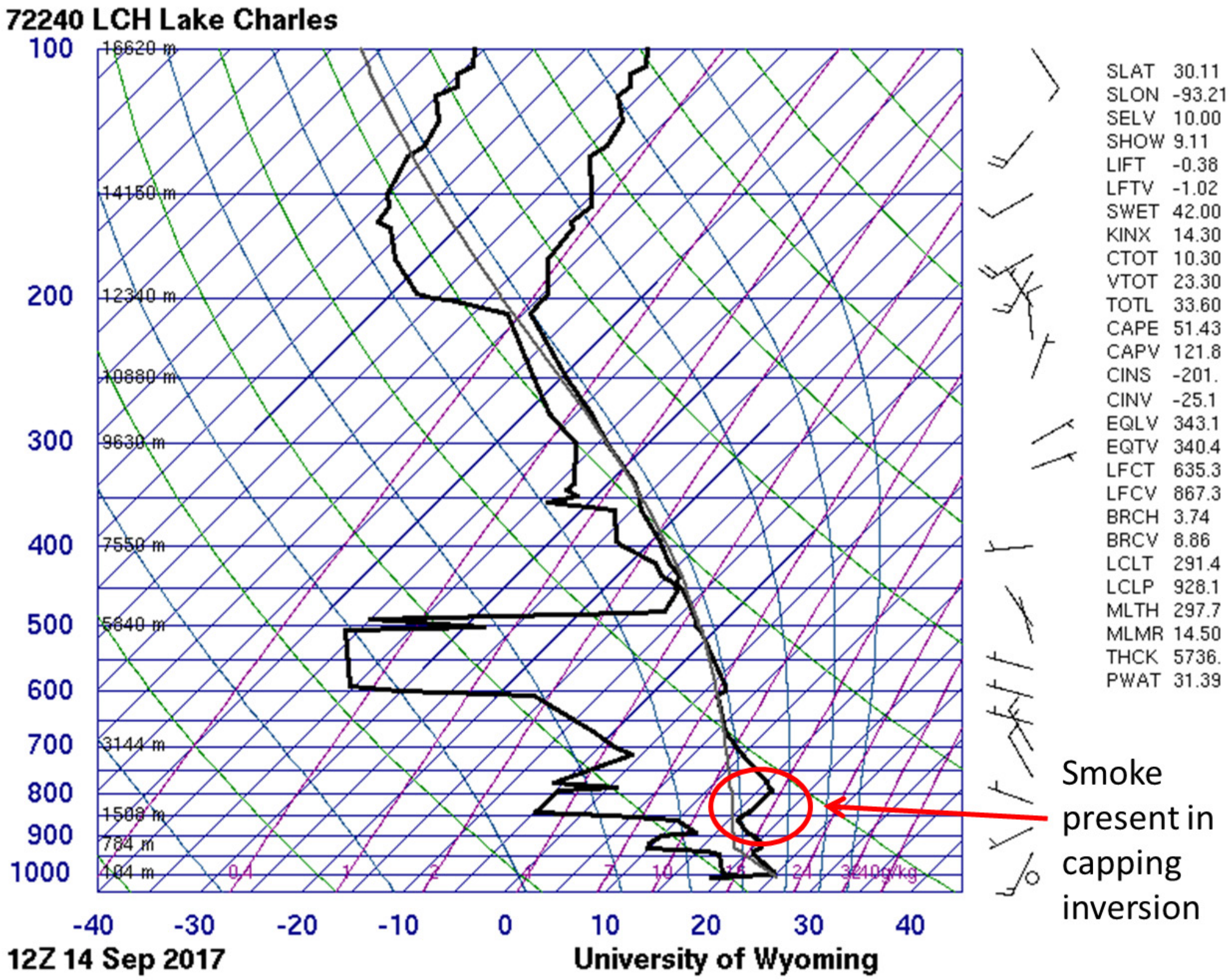

Figure 34. Skew-T plot showing temperature and humidity morning vertical profiles collected at Lake Charles, approximately 125 miles west of Baton Rouge on September 14, 2017, at 6:00 a.m. CST. The approximate vertical location of the smoke plume detected by CATS is indicated by a red circle. The temperature profile indicates the smoke is located in a capping inversion.

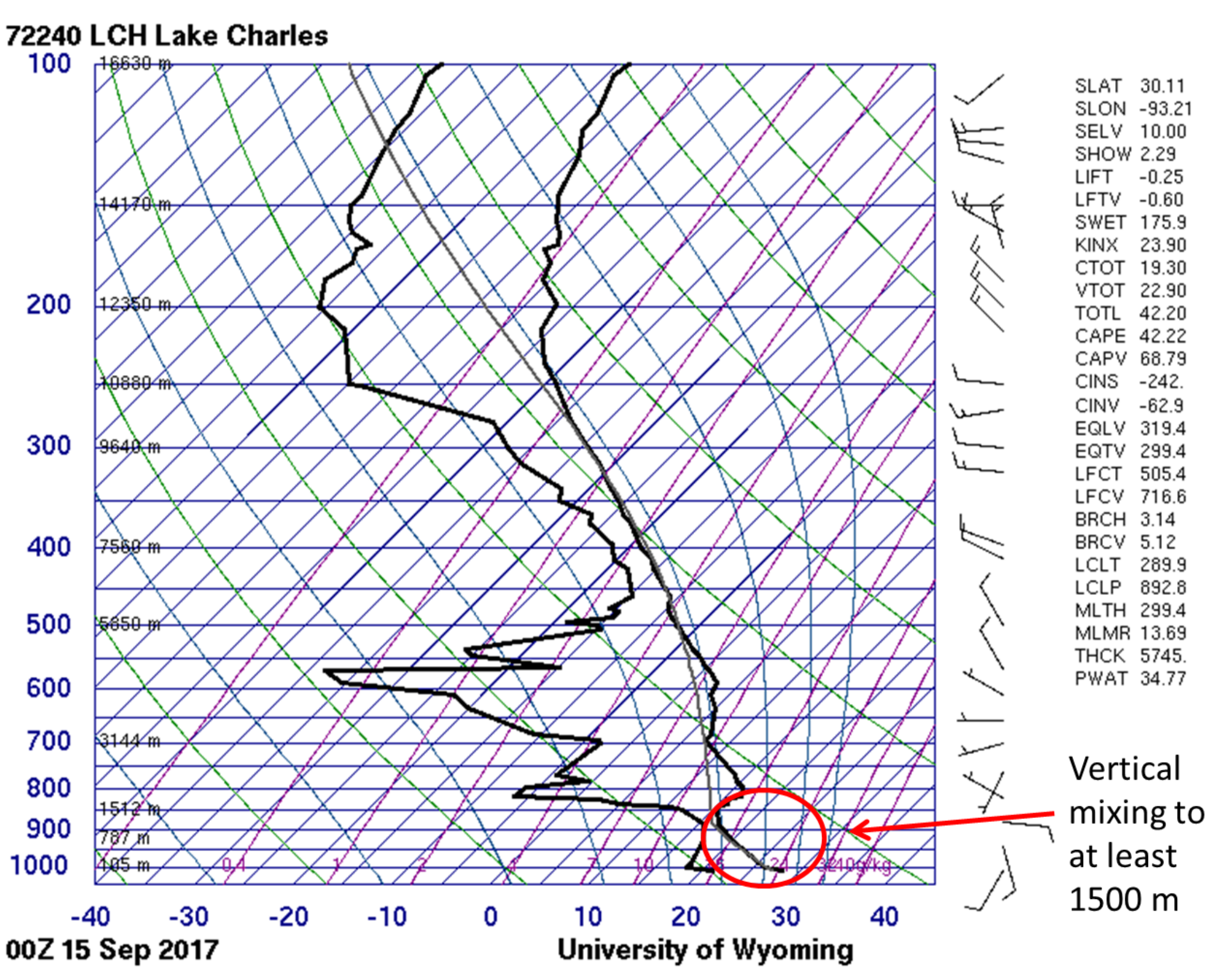

Figure 35. Skew-T plot showing temperature and humidity afternoon vertical profiles collected at Lake Charles, approximately 125 miles west of Baton Rouge on September 14, 2017, at 6:00 p.m. CST. The temperature profile indicates that vertical mixing occurred up to the height at which the smoke plume was present earlier in the day.

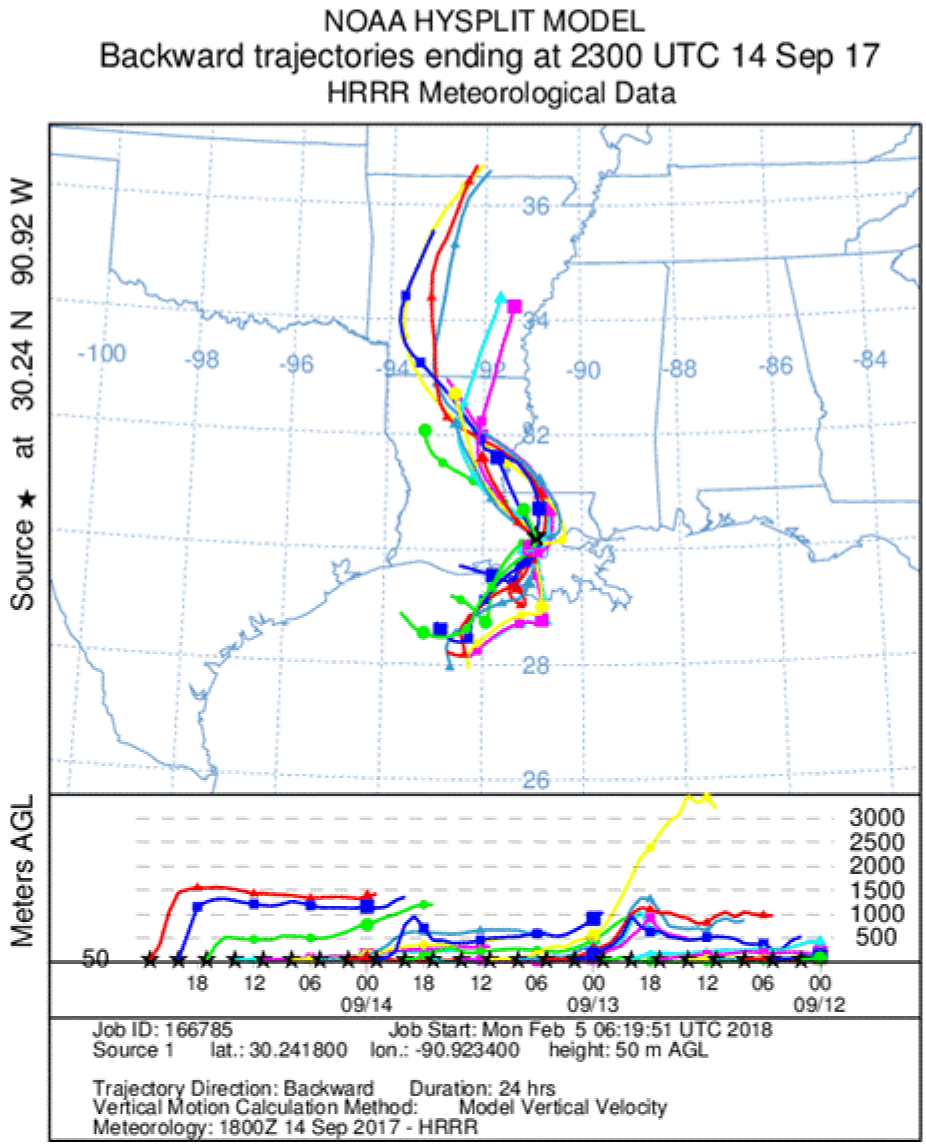

Figure 36. Twenty-four hour backward trajectories from Baton Rouge on September 12-14, 2017.

3.6 Supporting Pollutant Trends and Diurnal Patterns

Smoke maps, HYSPLIT trajectories, visible satellite imagery, and satellite retrievals of AOD and CO show strong evidence of smoke transport from fires burning in the northwestern United States to Louisiana. Furthermore, vertical aerosol profiles from satellite and mixing height information suggest that smoke was present over the site prior to the day of September 14, and that downward vertical mixing occurred from the altitude at which the smoke was observed.

Ground measurements of wildfire plume components (e.g., $PM_{2.5}$, CO, NO_x and VOCs) can be used to further demonstrate that smoke impacted ground-level air quality if elevated concentrations or unusual diurnal patterns are observed. We examined concentrations of $PM_{2.5}$, CO, NO_x, and speciated VOCs measured at the Capitol site in downtown Baton Rouge, approximately 20 miles northwest of Dutchtown. If $PM_{2.5}$, CO, NO_x, and VOCs were elevated at the time the smoke plume arrived in Baton Rouge, these measurements would provide additional supporting evidence of smoke impacts in Baton Rouge.

Twelve-hour average $PM_{2.5}$ concentrations showed a marked increase over the course of the day on September 14 (**Figure 37**), closely following the rise in ozone on that day. This provides support for the presence of smoke at the surface. Unusual spikes are observed in hourly NO_x and CO measurements at the same time of day that $PM_{2.5}$ concentrations increase, providing support for smoke impacts on September 14. Although spikes of total non-methane organic compounds (TNMOCs) also occurred, these increases are similar in magnitutde to increases observed on nearby dates, suggesting that smoke impacts could not be discerned from local sources.

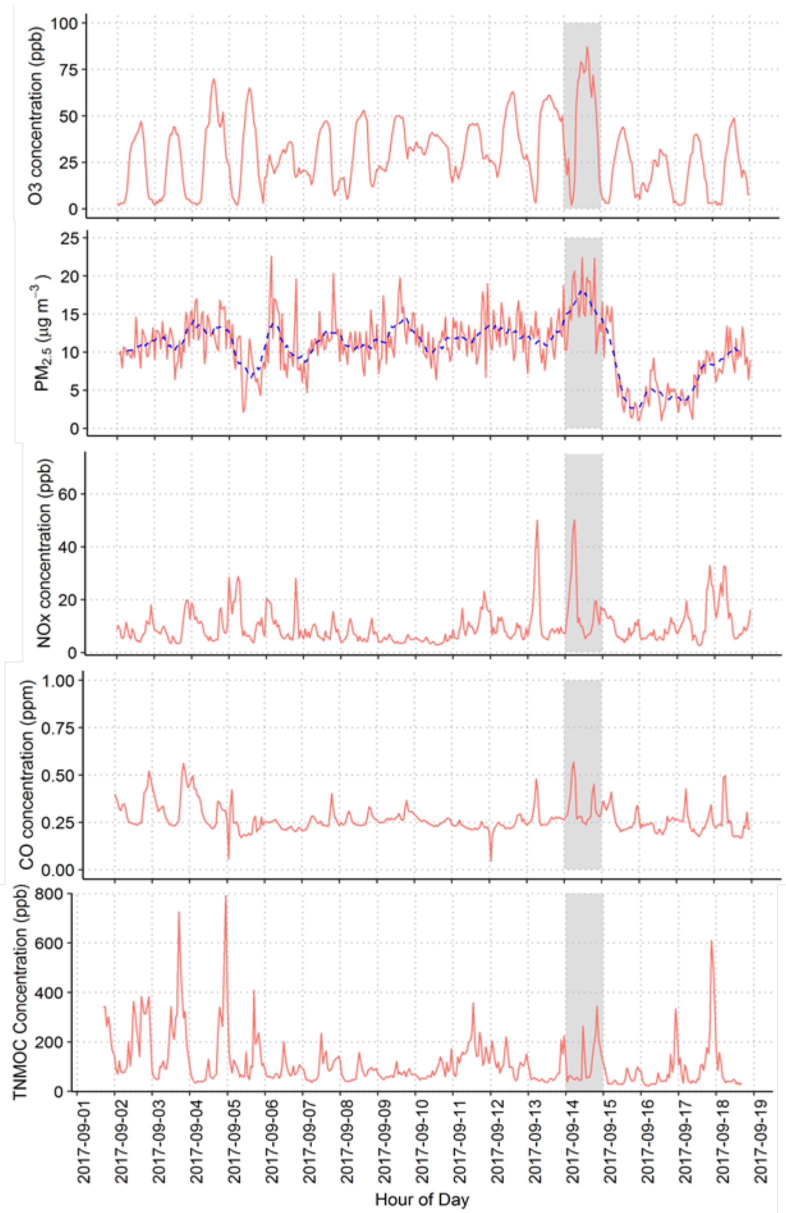

Figure 37. Hourly concentrations of ozone, $PM_{2.5}$, NO_x, CO, and total non-methane organic compound (TNMOC). Ozone is shown for the Dutchtown site, while all other measurements were collected at the Capitol Site. The blue dashed line indicates 12-hr rolling average $PM_{2.5}$ concentrations. The grey bar indicates September 14, 2017.

Unusual diurnal patterns of supporting measurements can provide evidence that smoke impacted Baton Rouge air quality. In Figure 38, average diurnal patterns for five years of ozone and $PM_{2.5}$ data are displayed for the Downtown Baton Rouge Capitol monitoring site. On a typical day, the diurnal profiles of ozone and $PM_{2.5}$ follow different patterns. When ozone concentrations are increasing in midday, $PM_{2.5}$ concentrations show little variation. In contrast, on September 14, 2017, $PM_{2.5}$ rose and fell with ozone. While on average days both $PM_{2.5}$ and ozone concentrations decline between

2:00 p.m. and 7:00 p.m., concentrations of both pollutants remained at elevated levels throughout that period on September 14. Figure 39 shows the measurements of ozone at the Dutchtown monitoring site (22-005-0004) and $PM_{2.5}$ at the Downtown Baton Rouge Capitol monitoring site (22-033-0009) on September 14, 2017. Ozone and $PM_{2.5}$ measurements show the correspondence between the two pollutants and a significant deviation of $PM_{2.5}$ from its average diurnal pattern. This is a clear indication that ozone concentrations, along with concentrations of other pollutants, were impacted by wildfire emissions.

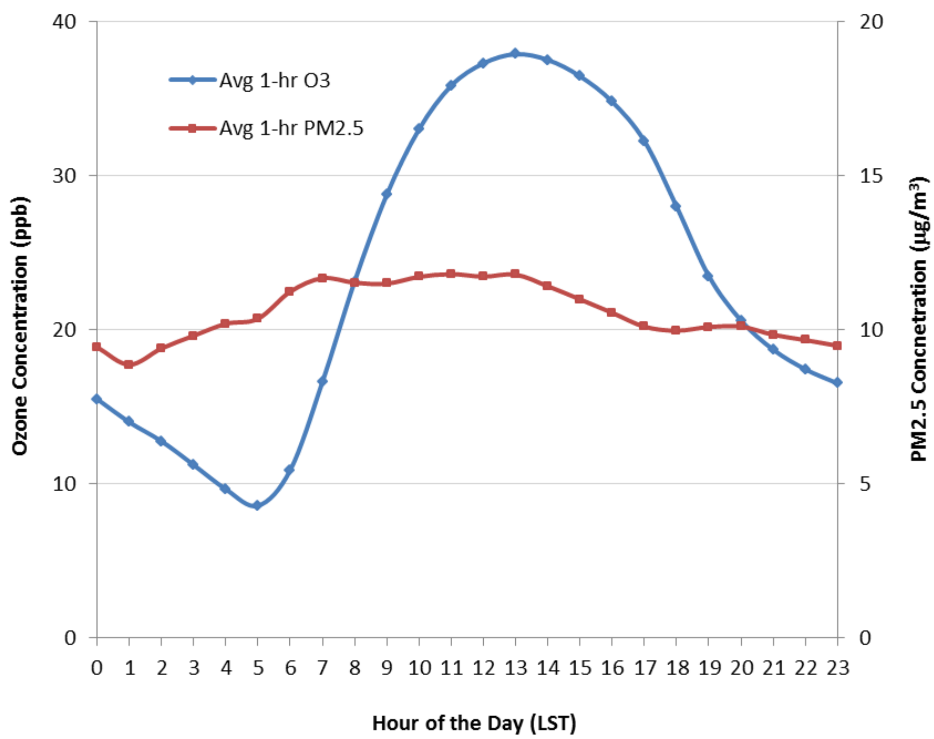

Figure 38. Average diurnal profile for ozone and $PM_{2.5}$ (May-September, 2013-2017) for the Downtown Baton Rouge Capitol monitoring site.

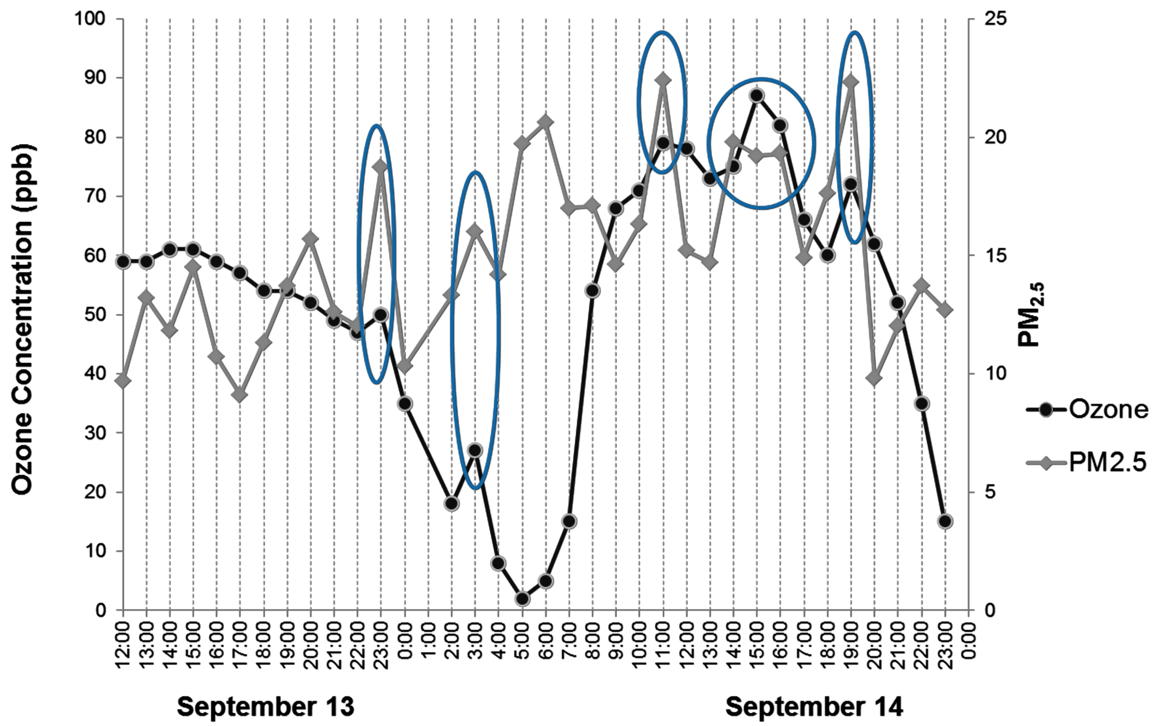

Figure 39. Hourly ozone (Dutchtown) and $PM_{2.5}$ (Capitol) concentrations for September 2017. Circles indicate time-coincident peaks in $PM_{2.5}$ and ozone.

Figure 40 shows the September 14, 2017, diurnal profile for ozone and CO concentrations at the Downtown Baton Rouge Capitol monitoring site. Also provided in this plot is the average diurnal profile for CO (2013-2017). Unlike $PM_{2.5}$, which rose and fell with ozone concentrations on September 14, 2017, CO follows its normal diurnal pattern. However, the level of CO measured on September 14 is higher than average throughout the day, which in part may reflect the impact of smoke. CO mixing ratios greater than 0.3 ppm have been considered as indicative of smoke impacts elsewhere (Lindaas et al., 2017). The CO mixing ratio at the Capitol site on September 14 exceeded 0.5 ppm for two morning hours and remained above 0.25 ppm for most of the day. The value recorded at 6:00 a.m. on September 14 was the highest CO value measured between September 2 and September 19. As with CO, the diurnal pattern of NO_x shows that NO_x concentrations measured in the morning of September 14 were substantially higher than on average days in August and September and higher than average for exceedance days (**Figure 41**). High CO and NO_x concentrations are consistent with either local emissions or transported smoke.

In addition to patterns for $PM_{2.5}$, CO, and NO_x, other pollutant patterns were investigated for noteworthy changes in pollutant concentrations on September 14. Appendix B provides VOC/NO_x ratios, CO/NO_x ratios, and time series plots surrounding September 14, 2017, for speciated VOC measurements. Ratios of VOC/NO_x can indicate key causes of high ozone. Low VOC/NO_x ratios indicate high relative NO_x concentrations. As seen with Figure 40 and Figure B-1, there were higher-than-normal NO_x concentrations and low/typical VOC concentrations on the episode day.

Reactive VOC species are unlikely to persist aloft over a 10-day transit period in midsummer. High photochemical reaction rates driven by long hours of sunlight will remove any species with a residence time of less than three days. Concentrations of longer-lived species like ethane and propane may be expected to be higher in smoke undergoing long range transport. On September 14, ethane (Figure B-4), n-butane (Figure B-13), and propane (Figure B-24) were slightly elevated relative to background concentrations in the area. This is consistent with higher concentrations of pollution regionally. Concentrations of more reactive species like benzene, alkenes, and other aromatics were low or typical. This indicates that the high concentrations of ethane are not from a local emissions source. The speciated VOC measurements therefore show that the elevated CO and NO_x are more likely to be associated with transported smoke than with local emissions sources.

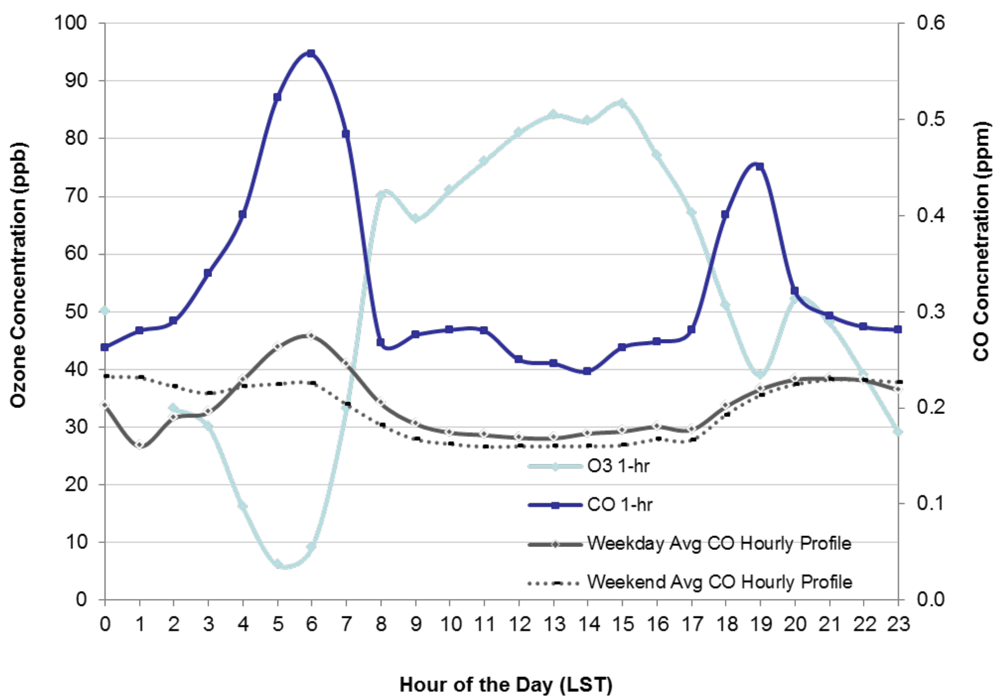

Figure 40. Diurnal profile for ozone and CO on Sept 14, 201,7 for the Downtown Baton Rouge Capitol monitoring site, as well as the average diurnal profile for CO (May-September, 2013-2017).

In addition to $PM_{2.5}$, CO, and NO_x, other pollutant patterns were investigated for noteworthy changes in pollutant concentrations on September 14. Appendix B provides VOC/NO_x ratios, CO/NO_x ratios, and time series plots surrounding September 14, 2017 for speciated VOC measurements. These measurements do not provide strong evidence for or against smoke impacts in Baton Rouge.

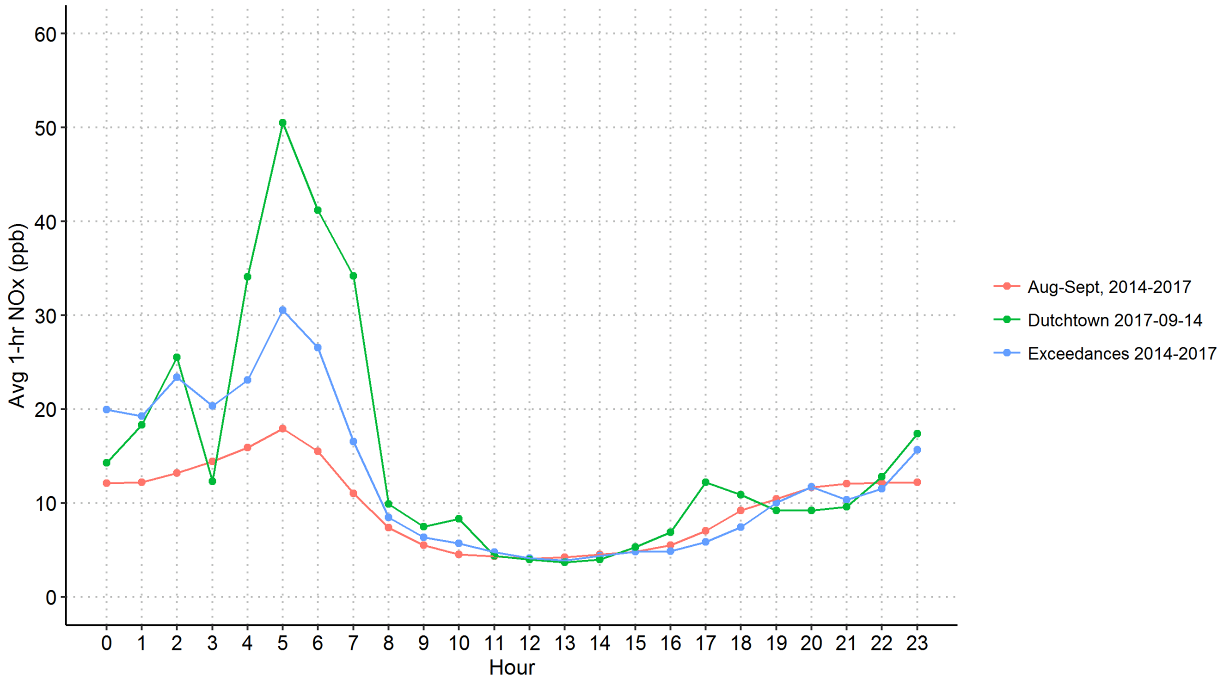

Figure 41. Diurnal profile of 1-hr NO_x measurements at Dutchtown on September 14, 2017 (green), average measurements at Dutchtown in August and September for 2014-2017 (red), and average measurements at Dutchtown on exceedance days for 2014-2017 (blue).

Our analysis shows unusual patterns $PM_{2.5}$ and also shows elevation in NO_2 and CO that are likely to be attributable to wildfire smoke. These analyses provide additional supporting evidence that wildfire smoke contributed to ozone concentrations at the Dutchtown site on September 14, 2017.

3.7 Smoke Emissions from Wildfires

Tier 2 analyses require calculation of the emissions of NO_x and reactive VOCs divided by the distance (Q/d) as the first of two key factors. Sonoma Technology, Inc., is the contractor to EPA for calculating wildland fire emissions for the National Emissions Inventory (NEI). To support the Q/d calculations for the September 14, 2017 smoke event, we prepared wildfire smoke emissions using the same methods normally used for the NEI (Huang et al., 2017), in accordance with the EPA's exceptional event guidance. Specifically, we used the SmartFire/BlueSky Framework approach (U.S. Environmental Protection Agency, 2016c) to prepare emissions for fires based on data available between August 27 and September 16, 2017, for the continental United States only.

We collected fire activity data sets from both satellite detections and agency reports. Data sources included Geospatial Multi-Agency Coordination (GeoMAC) Group wildfire polygons,[3] National

[3] GeoMAC data were obtained from https://rmgsc.cr.usgs.gov/outgoing/GeoMAC/historic_fire_data/.

Association of State Foresters fire reports,[4] USDA Forest Service prescribed fire data from the Forest Service Activity Tracking System (FACTS),[5] Louisiana state fire data,[6] and NOAA Hazard Mapping System fire detections.[7] We combined these data sets using the SmartFire reconciliation system and calculated emissions from the fires using the BlueSky Framework (Figure 42). Fire emissions included NO_x and total VOCs. Total VOCs were converted to reactive VOCs by multiplying by a factor of 0.6, as recommended in the EPA exceptional event guidance. Fire activity data and emissions were quality-controlled through analyst review and automated control methods.

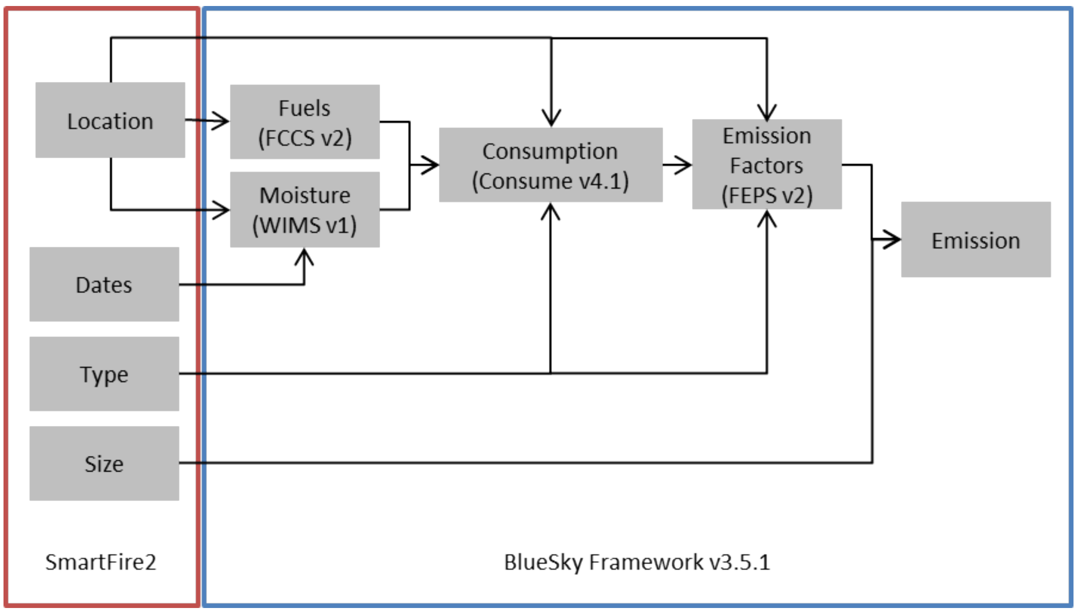

Figure 42. Model chain used to develop emissions for the contiguous United States based on fire activity between August 27 and September 16, 2017.

Fire emissions data were used to calculate the Q/d values for fires that could have impacted air quality in Baton Rouge. We calculated 24-hr HYSPLIT back trajectories from the monitor location starting on each hour of the day of the exceedance as well as the day prior to the exceedance. We then created a buffer of uncertainty around each trajectory based on 25% of the distance traveled by the trajectory, based on the uncertainty reported for HYSPLIT modeling (Draxler, 1991). All fires falling within the uncertainty buffer of one or more trajectories were then used to calculate an individual Q/d value for each day on which emissions occurred. In addition, for each day we calculated the aggregate Q/d value for all fires falling within the uncertainty buffer (Figure 43). For September 14 in Baton Rouge, the largest calculated Q/d value for an individual fire was 0.79. The aggregate Q/d for all fires on September 14 was 5.36. These Q/d values fall far below the threshold of 100 set by the exceptional event guidance for a Tier 2 exceptional event. Q/d calculations, because

[4] NASF data were obtained from https://fam.nwcg.gov/fam-web/.
[5] FACTS data was obtained from http://data.fs.usda.gov/geodata/edw/datasets.php.
[6] Fire data were obtained from https://www.arcgis.com/home/item.html?id=7df93214bdb84217b7fb6db5cfc6a0a5.
[7] HMS data were obtained from ftp://satepsanone.nesdis.noaa.gov/FIRE/HMS/GIS/ARCHIVE/.

they rely on only 24-hr back trajectories, generally reflect the impact of local fires. The low Q/d values calculated for Baton Rouge on September 14, 2017, suggest that local fires likely played only a small role, if any, in the high ozone measurements on September 14 in Baton Rouge. Instead, as our other analyses show, long-range transport of smoke from fires burning in the northwestern United States was likely to have contributed significantly to the ozone exceedance on September 14.

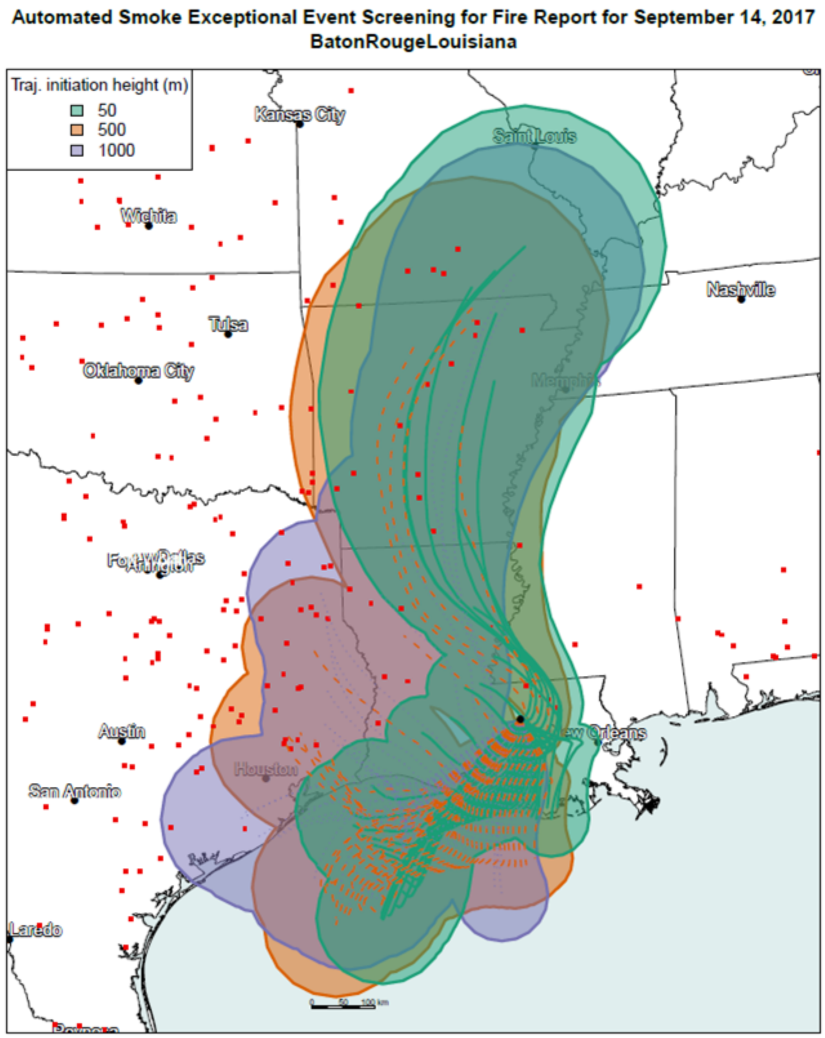

Figure 43. Map showing the approach used to identify fires for the Q/d calculation for September 14. 2017. Fires active on September 13 or September 14 are shown as red squares. Twenty-four hour back trajectories are shown as solid or dotted lines. The starting height of the back trajectory is indicated by the color. Uncertainty buffers, calculated as 25% of the distance traveled by the trajectory, are shown as colored polygons, where the color indicates the starting height of the trajectory at Baton Rouge. Fires falling within one or more uncertainty buffers were used to calculate individual and aggregate Q/d values.

Using the SmartFire-reconciled fire activity data, we identified 24 fires in the northwestern United States that burned areas larger than 10,000 acres[8] and that were active on September 14, 2017 (**Figure 44**). All fires shown in Figure 44 were actively burning on September 14, and the majority started on or before August 27, 2017, burning over multiple days leading up to September 14. In total, these fires accounted for over 1,200,000 acres burned in Washington, Oregon, California, Idaho, and Montana. These fires, in conjunction with smaller fires not named here, produced the large smoke plume that was transported over the United States, as observed via several sources of satellite data.

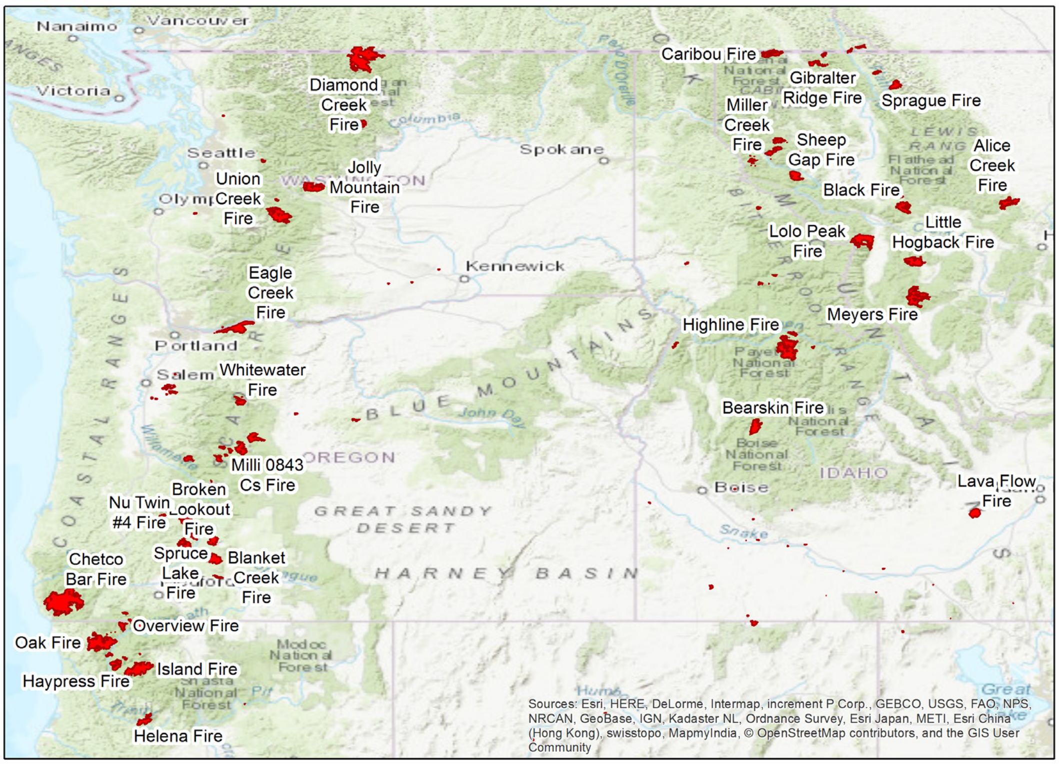

Figure 44. Map of wildfires active in the northwestern United States on September 14, 2017. The names of fires greater than 10,000 acres are shown.

[8] Fires starting on or before August 27 as shown in the map above included the Alice Creek, Bearskin, Blac, Blanket Creek, Broken Lookout, Caribou, Chetco Bar, Diamond Creek, Gibralter Ridge, Haypress, Highline, Island, Jolly Mountain, Little Hogback, Lolo Peak, Meyers, Milli 0843 Cs, Nu Twin #4, Oak, Overview, Sprague, Spruce Lake, Union Creek, and Whitewater Fires.

4. Discussion of Findings

The analyses conducted provide evidence supportive of smoke impacts on ozone concentrations in Baton Rouge on September 14, 2017. We show that (1) a substantial amount of smoke was transported from wildfires in the northwestern United States across the central and southern United States to Louisiana in the days leading up to September 14, 2017, (2) smoke aloft was transported to the surface on September 14, 2017, and (3) smoke impacted ground-level pollution measurements in the Baton Rouge area on September 14, 2017. These analyses were conducted to address Tier 1 and Tier 2 exceptional event demonstration requirements, and the results are summarized in **Table 7**. The results are supportive of a Tier 3 exceptional event demonstration.

We identified 24 wildfires that burned over 10,000 acres each during the weeks leading up to September 14 and that remained active until at least September 14. The fires together burned over 1.2 million acres. These wildfires emitted a large plume of smoke that is visible in satellite images and in satellite measurements of AOD and CO. These images and measurements show that the smoke was transported over nearly a week's time to Louisiana. In addition, HYSPLIT trajectories show that the smoke was transported from wildfires in Idaho to the central United States in the days prior to September 14. Additional trajectories show transport of air masses eastward from Texas over the Gulf of Mexico to Louisiana on September 14. In visible imagery, and in CO and AOD measurements from satellite, the eastward movement of smoke from Texas and the Gulf is apparent. These data show that wildfire smoke was present over Louisiana on the day of the event, September 14.

Additional analyses show that vertical mixing and downward transport of smoke aloft to the surface occurred over September 13 and 14. At approximately 11:00 p.m. CST on September 13, CATS aerosol data show that smoke was present over Louisiana at an altitude of 1,400 m to approximately 5,000 m. The approximate elevation of the smoke is additionally supported by meteorological evidence. Ceilometer and radiosonde mixing height measurements show that vertical mixing from the altitude at which the smoke was present occurred on September 13 and 14. Additional evidence supporting this activity is provided by HYSPLIT back trajectories run for September 14, which show downward transport on September 14 from an altitude of approximately 1,500 meters. Evidence is strong that smoke aloft over Baton Rouge was mixed downward to the surface.

The arrival of smoke at the surface on September 14 impacted air quality in Baton Rouge. Exceptionally high area-wide ozone concentrations were observed on that day. The exceedance at the Pride monitoring site represented the only time that monitor showed an ozone exceedance between July and December of 2013 through 2017. In addition, supporting measurements of $PM_{2.5}$, CO, and NO_x concentrations indicate the presence of smoke.

Together, these analyses demonstrate that ozone concentrations in Baton Rouge were impacted on September 14 by wildfire smoke transported from fires in the northwestern United States.

Table 7. Summary of tier-specific analyses for smoke/ozone exceptional events and our findings.

Tier	Requirements	Finding
1	• Comparison of fire-influenced exceedance with historical concentrations • Evidence that fire and monitor meet one of the following key factors: – Key Factor #1: Seasonality differs from typical season, or – Key Factor #2: Ozone concentrations are 5-10 ppb higher than non-event-related concentrations • Evidence of transport of fire emissions to monitor: – Trajectories of fire emissions, or – Satellite images and supporting evidence from surface measurements	• The September 14. 2017 ozone exceedance occurred during typical ozone season. • Trajectories and satellite images and data support long range smoke transport into the area. • Trajectories, ceilometer mixing height measurements, and radiosonde data indicate vertical mixing and transport to the surface from the elevation at which smoke was present.
2	• All Tier 1 requirements • Key Factor #1: Fire emissions and distance of fires (Q/d > 100) • Key Factor #2: Comparison of the event-related ozone concentration with non-event-related high ozone concentrations (> 99th percentile over five years or top four highest daily ozone measurement) • Evidence that fire emissions affected the monitor (at least one of the following): – Visibility impacts – Changes in supporting measurements – Satellite NOx enhancements – Differences in spatial/temporal patterns	• The Q/d was well below 100. • Ozone concentration was >99th percentile over five years and the top measurement for the year • Surface PM2.5, NOx, and CO concentrations showed elevated concentrations and/or changes in diurnal profile consistent with smoke impacts.

5. References

Draxler R.R. (1991) The accuracy of rrajectories during ANATEX calculated using dynamic model analyses versus rawinsonde observations. *Journal of Applied Meteorology*, 30, 1446-1467, doi: 10.1175/1520-0450(1991)030<1446:TAOTDA>2.0.CO;2, February 25. Available at https://journals.ametsoc.org/doi/abs/10.1175/1520-0450%281991%29030%3C1446%3ATAOTDA%3E2.0.CO%3B2.

Huang S., Pavlovic N., Rao V., and Larkin S. (2017) Development of the 2014 wildland fire National Emissions Inventory version 1. Presented at *2017 Smoke Management in the Northwest, Portland, OR, March 22,* by Sonoma Technology, Inc., Petaluma, CA. STI-6699.

Lindaas J., Farmer D.K., Pollack I.B., Abeleira A., Flocke F., Roscioli R., Herndon S., and Fischer E.V. (2017) Changes in ozone and precursors during two aged wildfire smoke events in the Colorado Front Range in summer 2015. *Atmos. Chem. Phys.*, 17, 10691-10707, doi: 10.5194/acp-17-10691-2017, September 12. Available at https://www.atmos-chem-phys.net/17/10691/2017/.

U.S. Environmental Protection Agency (2016a) 40 CFR Parts 50 and 51: Treatment of data influenced by exceptional events. Final Rule, October 3. Available at www.epa.gov/sites/production/files/2016-09/documents/exceptional_events_rule_revisions_2060-as02_final.pdf.

U.S. Environmental Protection Agency (2016b) Guidance on the preparation of exceptional events demonstrations for wildfire events that may influence ozone concentrations. Final report, September. Available at www.epa.gov/sites/production/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf.

U.S. Environmental Protection Agency (2016c) 2014 National Emissions Inventory, version 1. Draft technical support document, December. Available at https://www.epa.gov/sites/production/files/2016-12/documents/nei2014v1_tsd.pdf.

Appendix A. Historical Context for Ozone Concentrations in Baton Rouge

Historical context for ozone concentrations recorded at eight Baton Rouge ozone monitoring sites is provided in the following figures. Red dots indicate the measurements collected on September 14, 2017. The black dotted line on all plots indicates the 99th percentile at that site for 2013 through 2017. The plots show daily maximum 8-hr ozone concentrations in 2017, in 2013 through 2017, and in 2013 through 2017 by day of year.

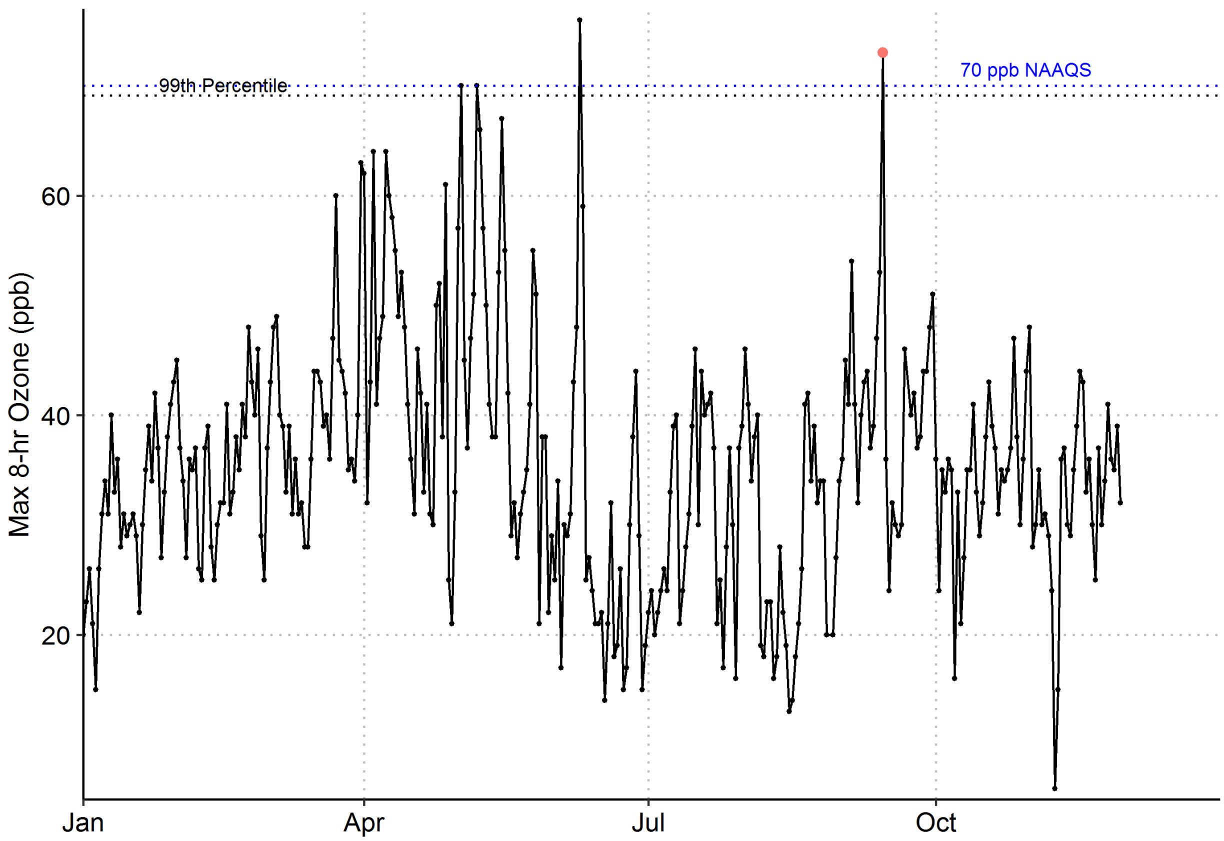

Figure A-1. Daily maximum 8-hr ozone concentrations at the LSU monitoring site (AQS ID 22-033-0003) in 2017.

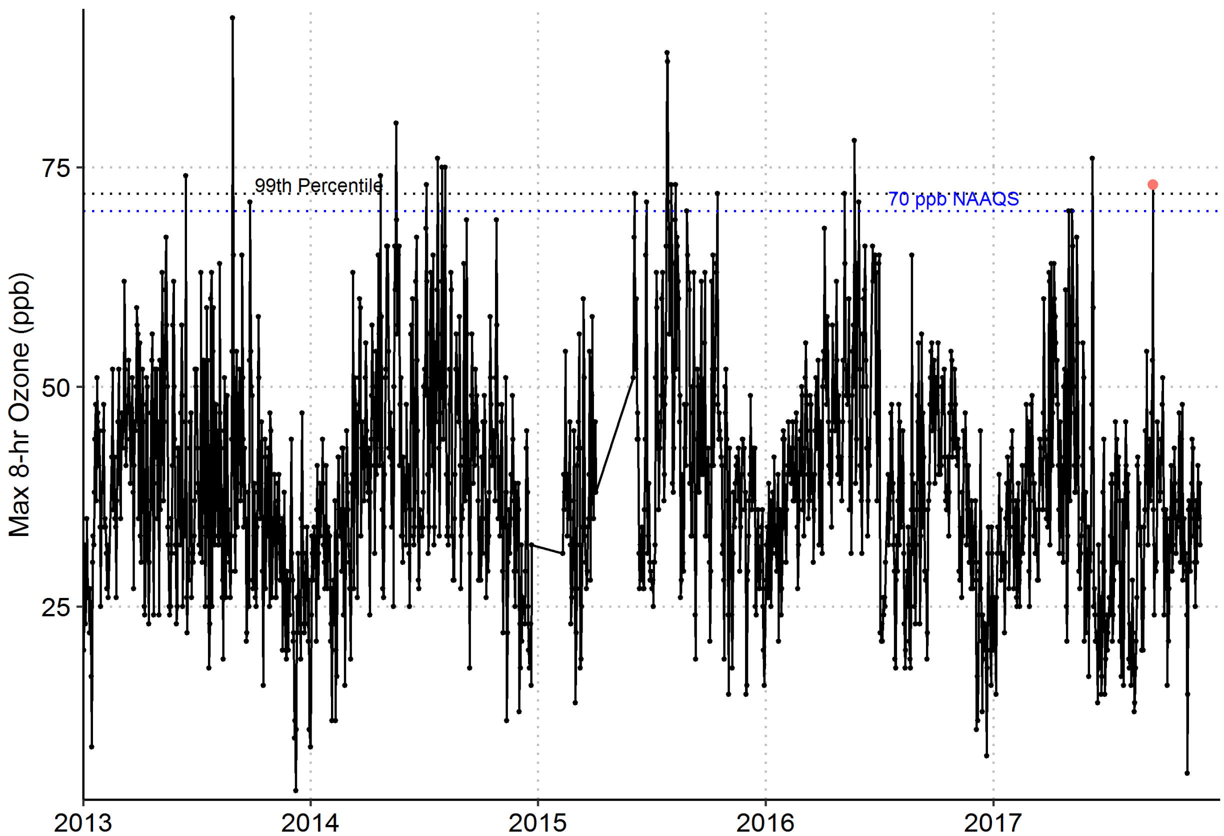

Figure A-2. Daily maximum 8-hr ozone concentrations at the LSU monitoring site (AQS ID 22-033-0003) from 2013 through 2017.

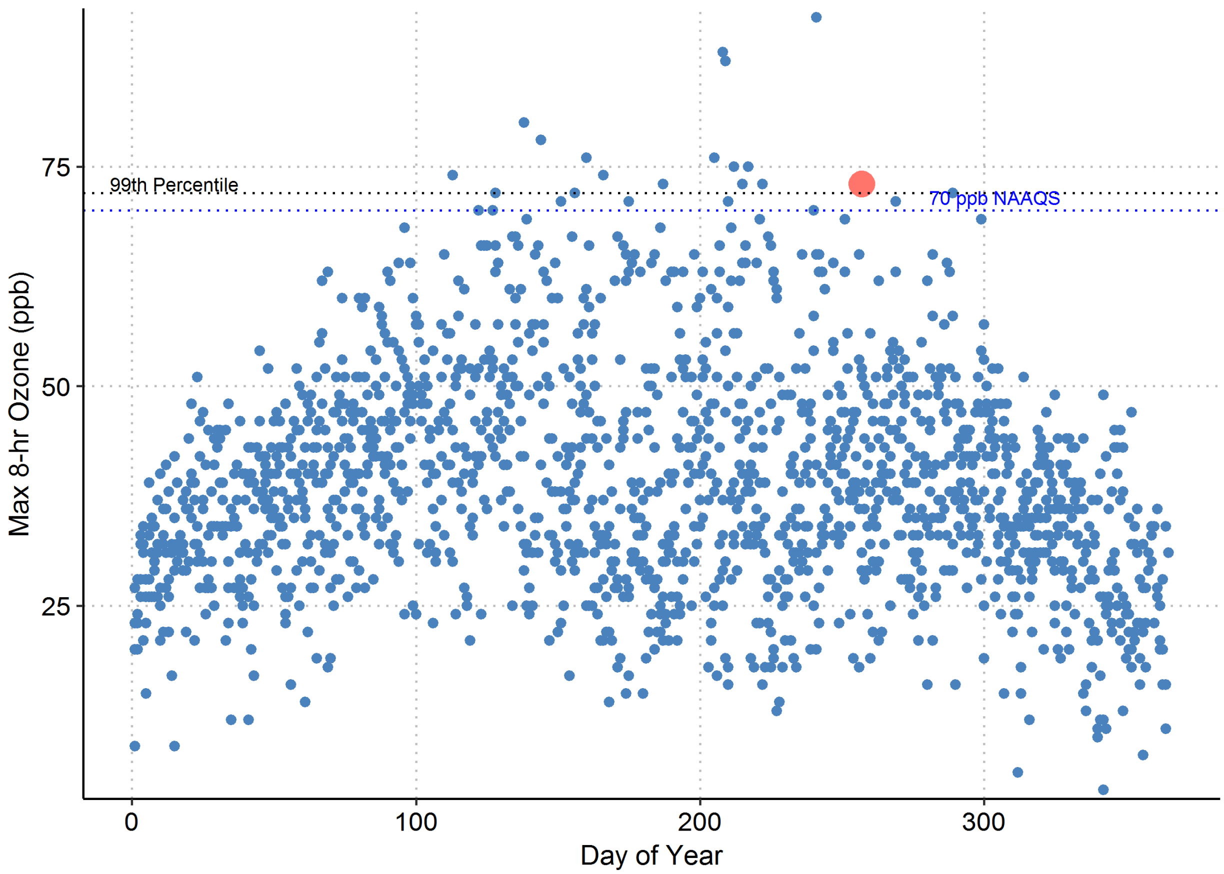

Figure A-3. Daily maximum 8-hr ozone concentrations at the LSU monitoring site (AQS ID 22-033-0003) from 2013 through 2017 by day of year.

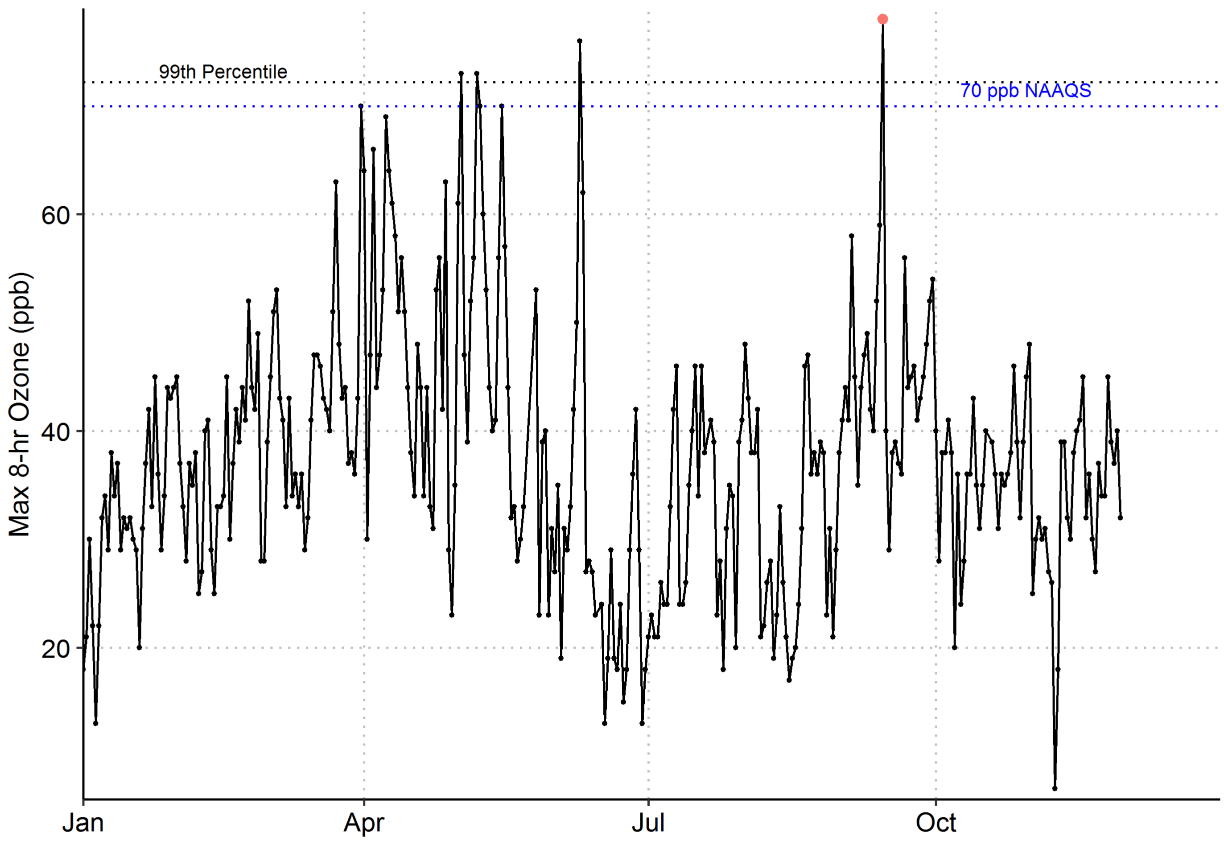

Figure A-4. Daily maximum 8-hr ozone concentrations at the Capitol monitoring site (AQS ID 22-033-0009) in 2017.

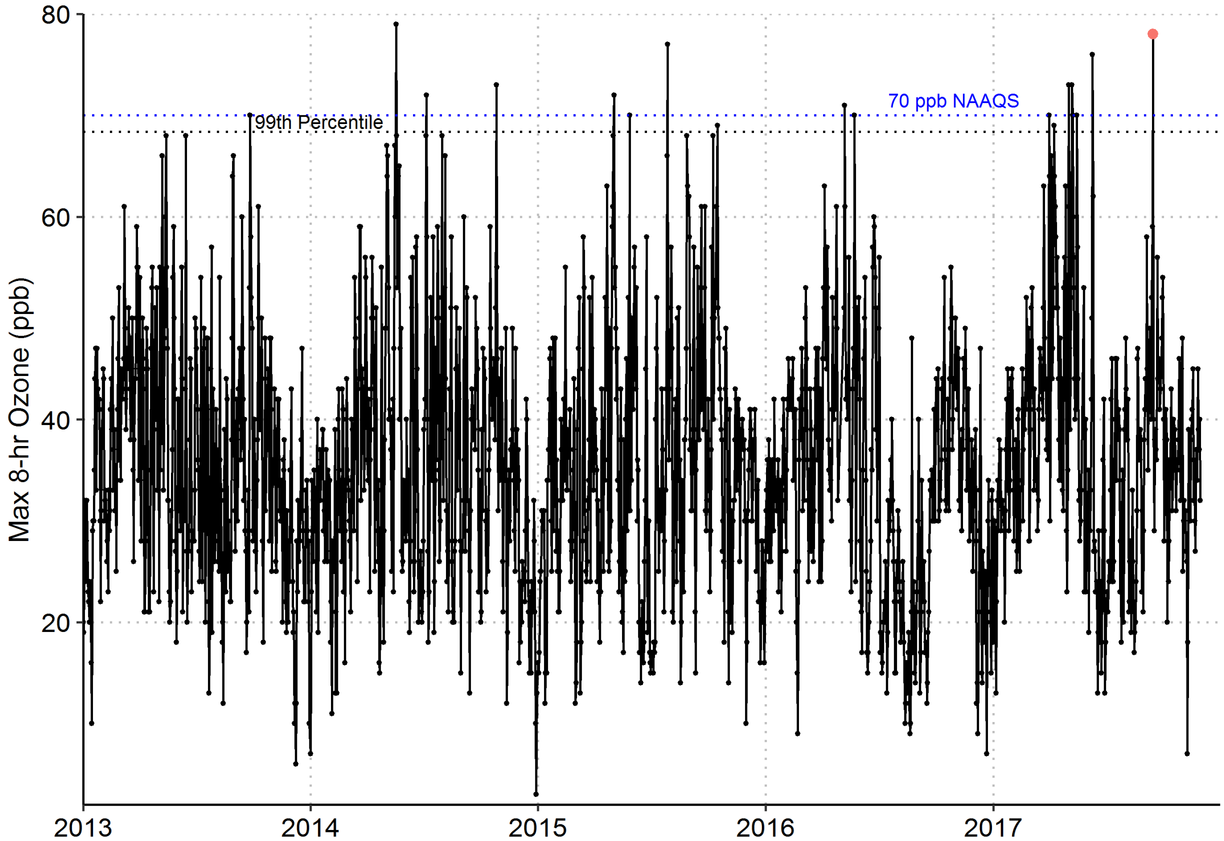

Figure A-5. Daily maximum 8-hr ozone concentrations at the Capitol monitoring site (AQS ID 22-033-0009) from 2013 through 2017.

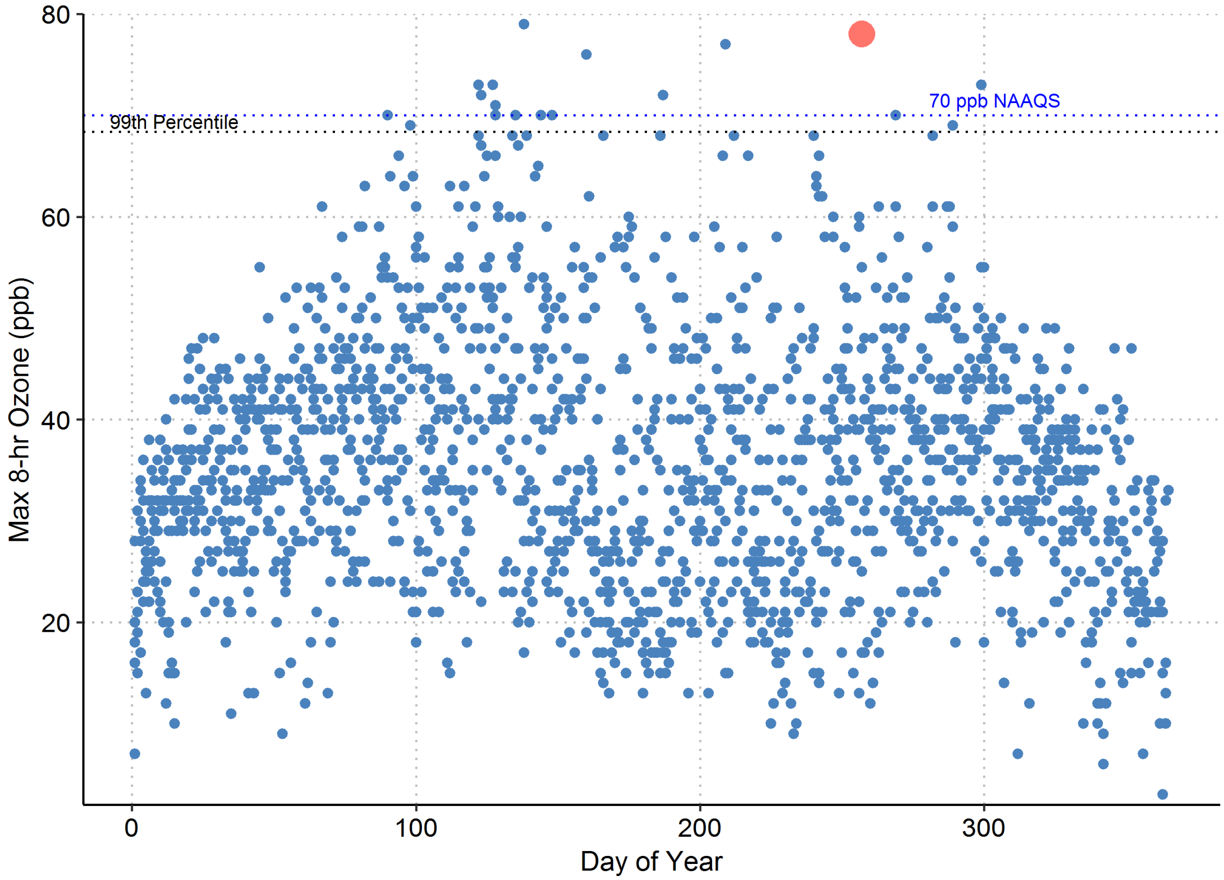

Figure A-6. Daily maximum 8-hr ozone concentrations at the Capitol monitoring site (AQS ID 22-033-0009) from 2013 through 2017 by day of year.

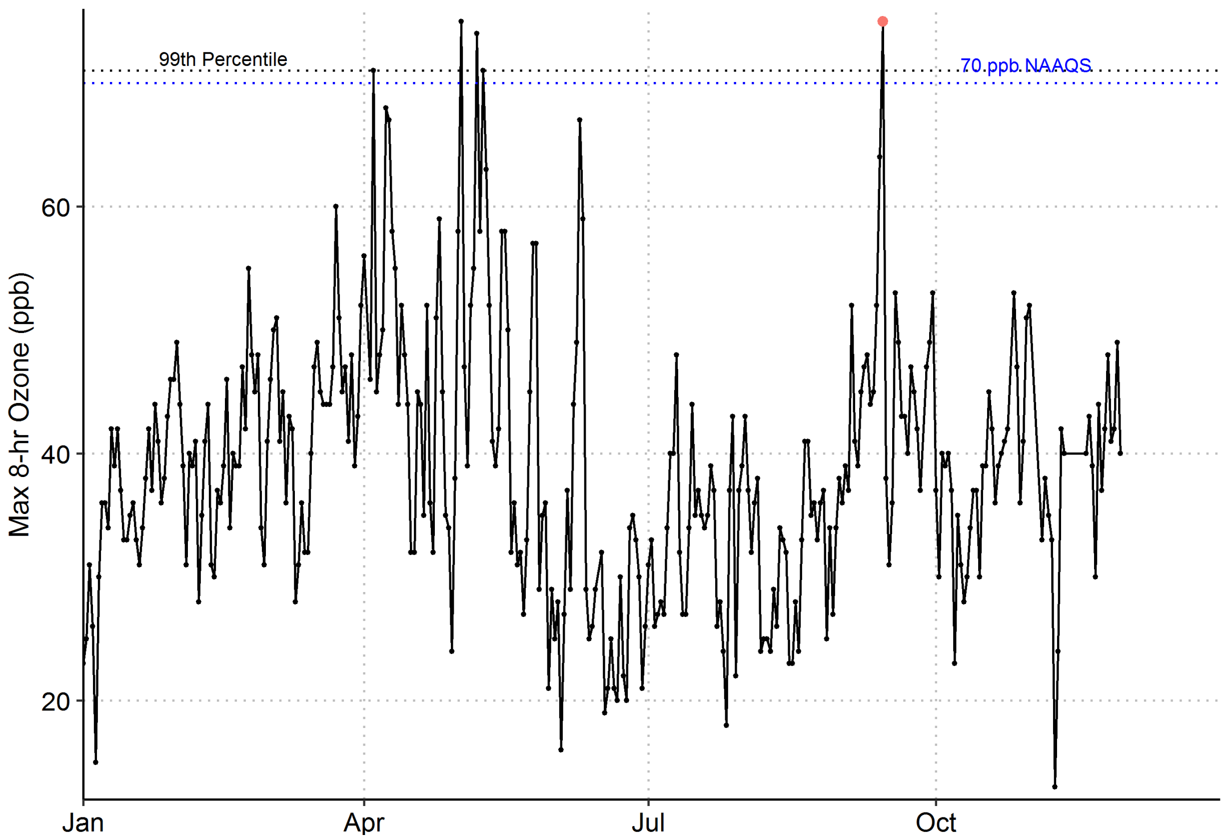

Figure A-7. Daily maximum 8-hr ozone concentrations at the Pride monitoring site (AQS ID 22-033-0013) in 2017.

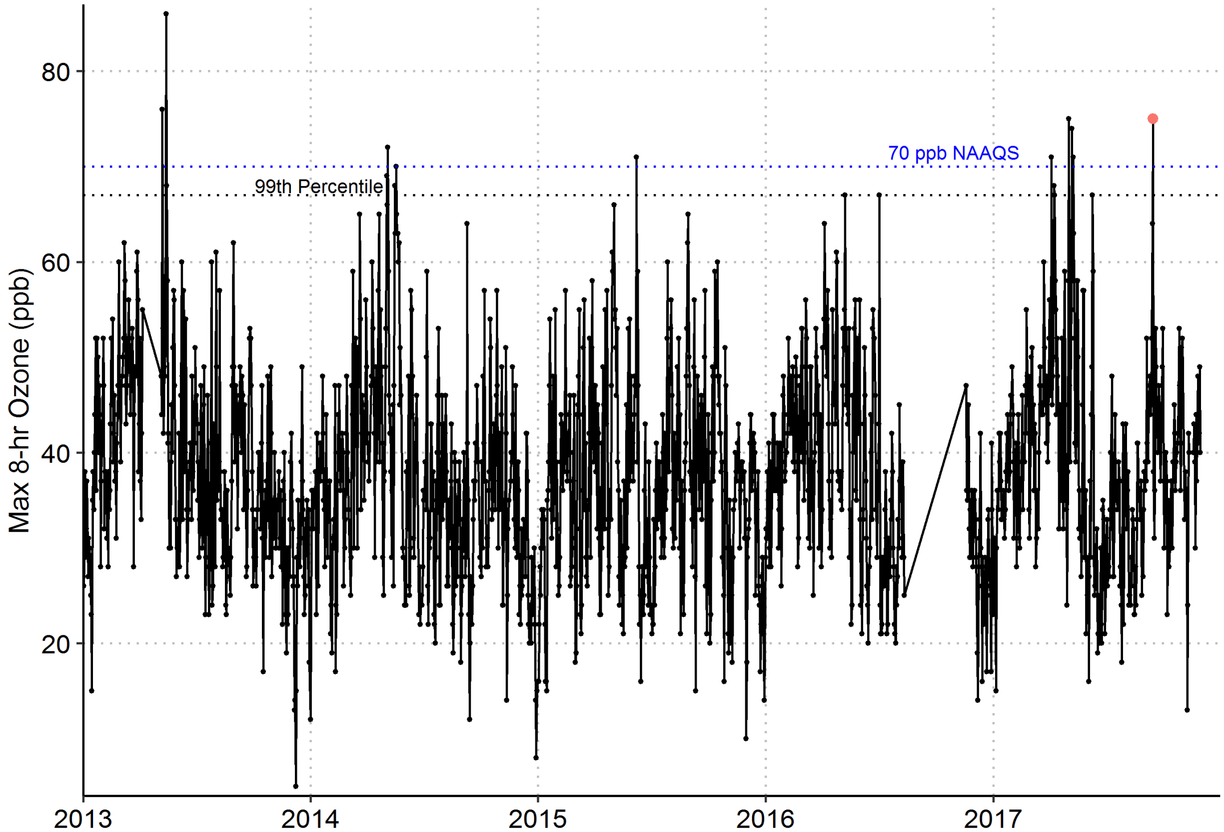

Figure A-8. Daily maximum 8-hr ozone concentrations at the Pride monitoring site (AQS ID 22-033-0013) from 2013 through 2017.

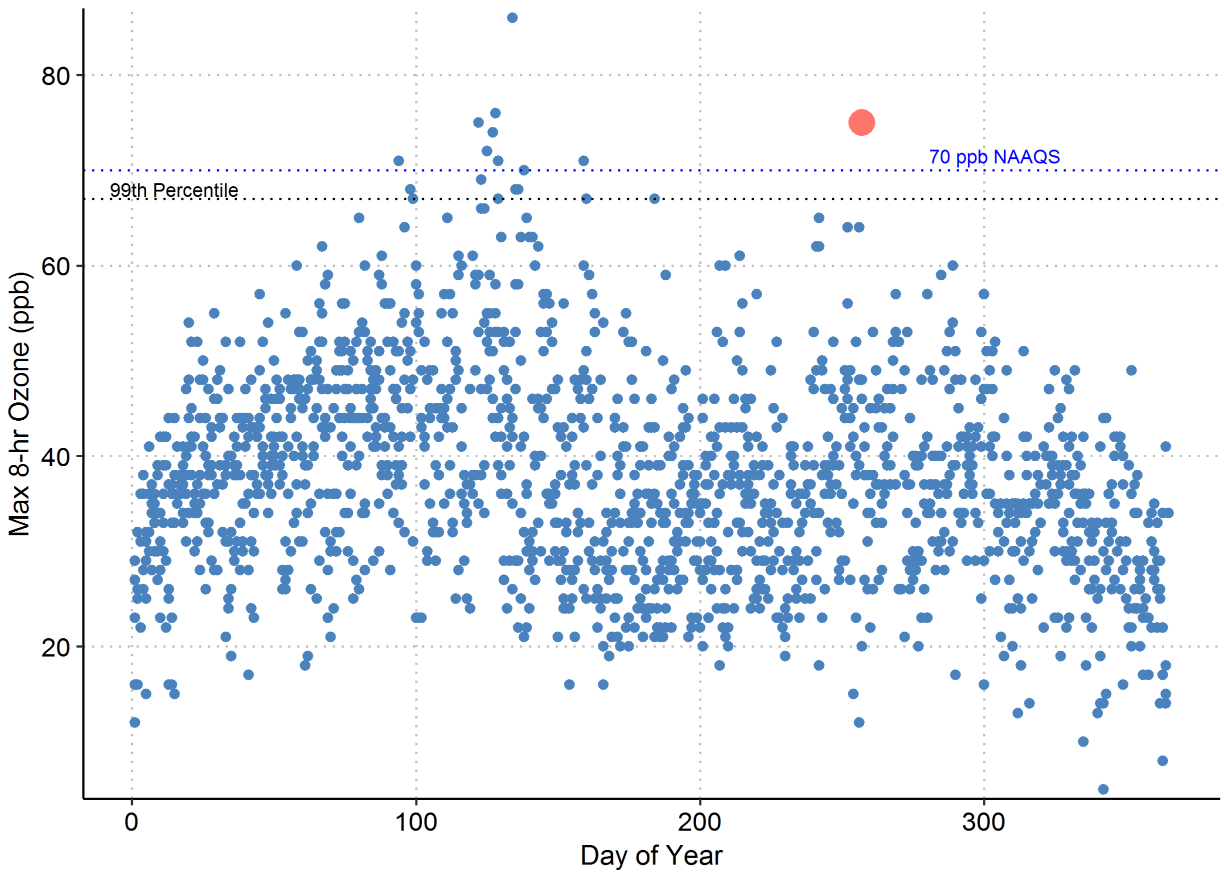

Figure A-9. Daily maximum 8-hr ozone concentrations at the Pride monitoring site (AQS ID 22-033-0013) from 2013 through 2017 by day of year.

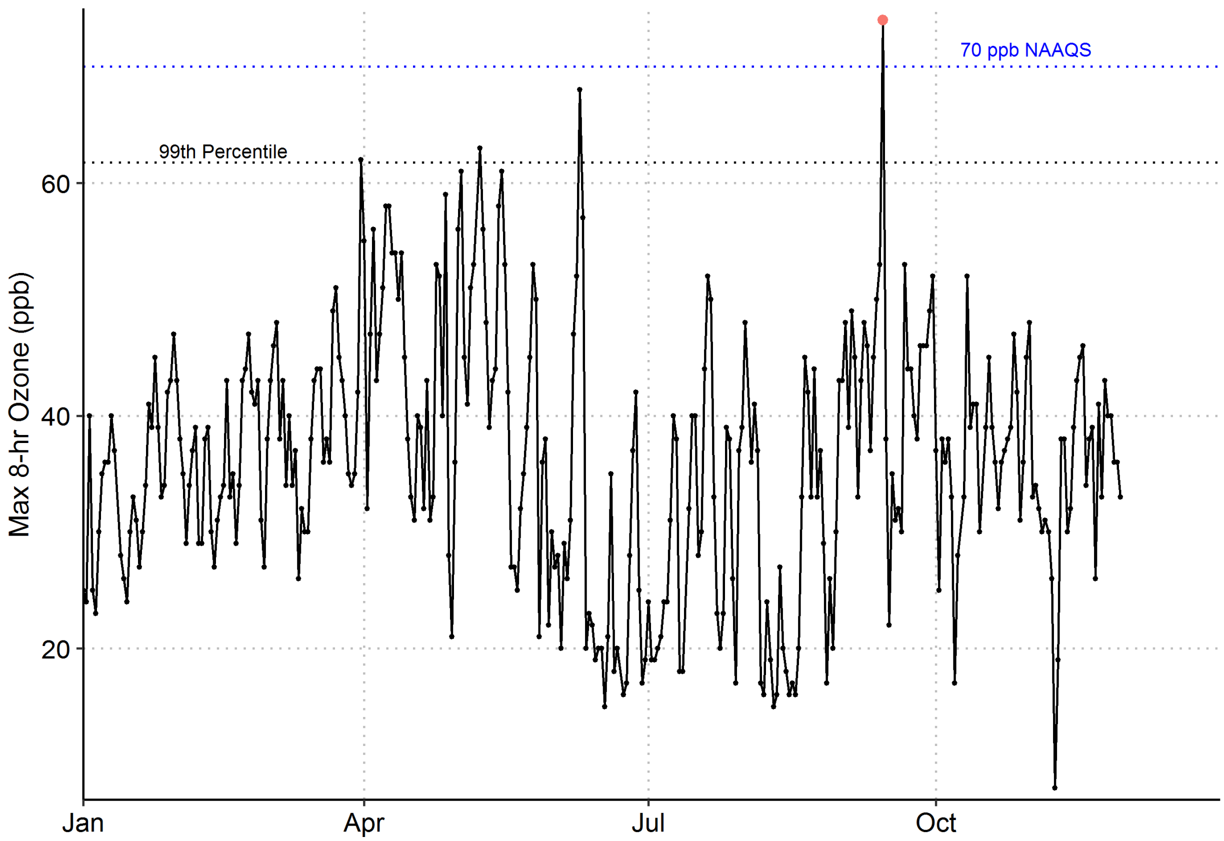

Figure A-10. Daily maximum 8-hr ozone concentrations at the Carville monitoring site (AQS ID 22-047-0012) in 2017.

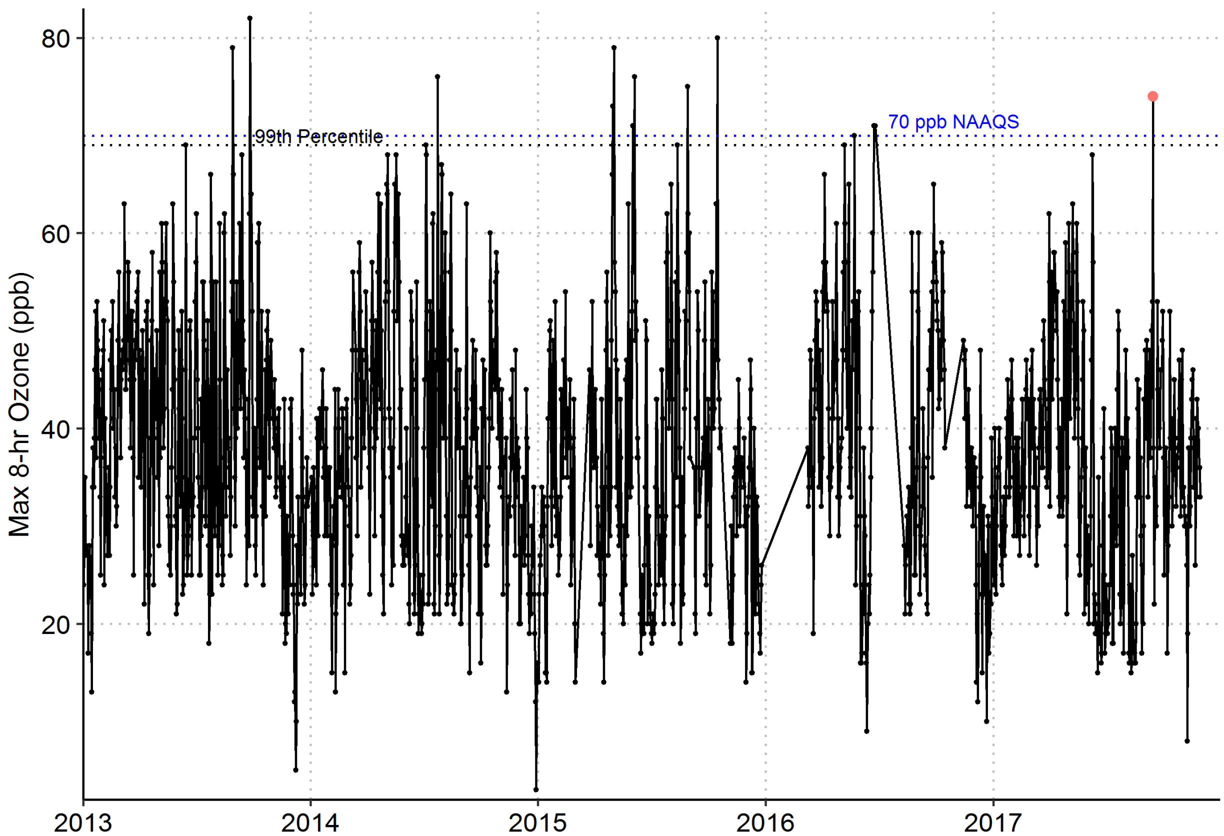

Figure A-11. Daily maximum 8-hr ozone concentrations at the Carville monitoring site (AQS ID 22-047-0012) from 2013 through 2017.

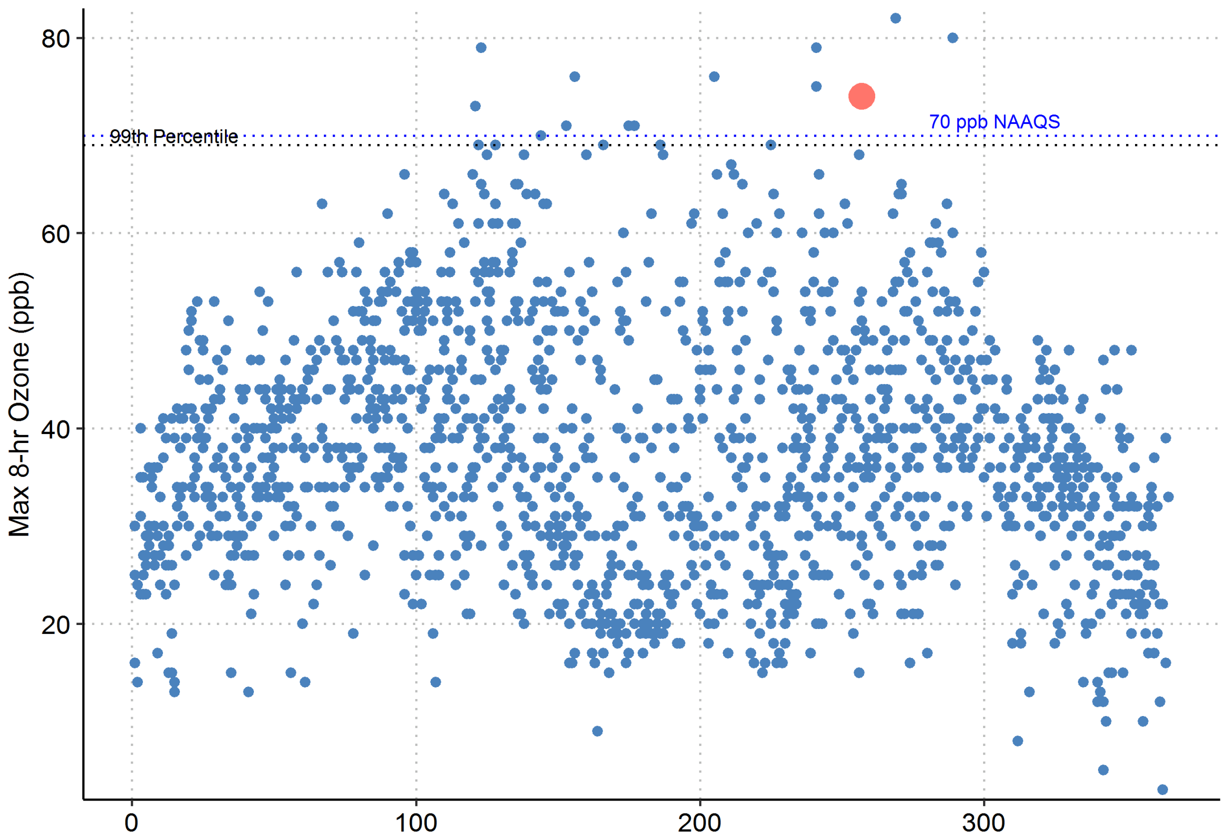

Figure A-12. Daily maximum 8-hr ozone concentrations at the Carville monitoring site (AQS ID 22-047-0012) from 2013 through 2017 by day of year.

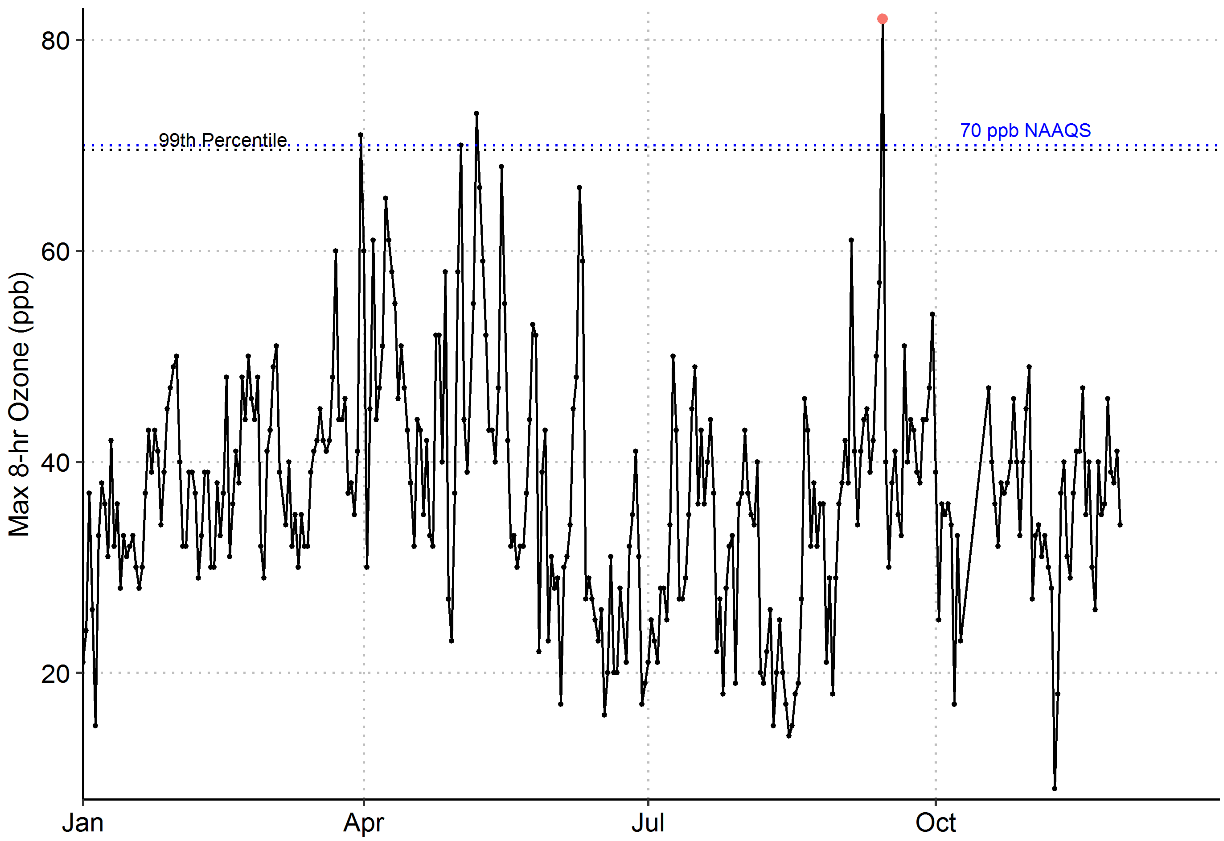

Figure A-13. Daily maximum 8-hr ozone concentrations at the Port Allen monitoring site (AQS ID 22-121-0001) in 2017.

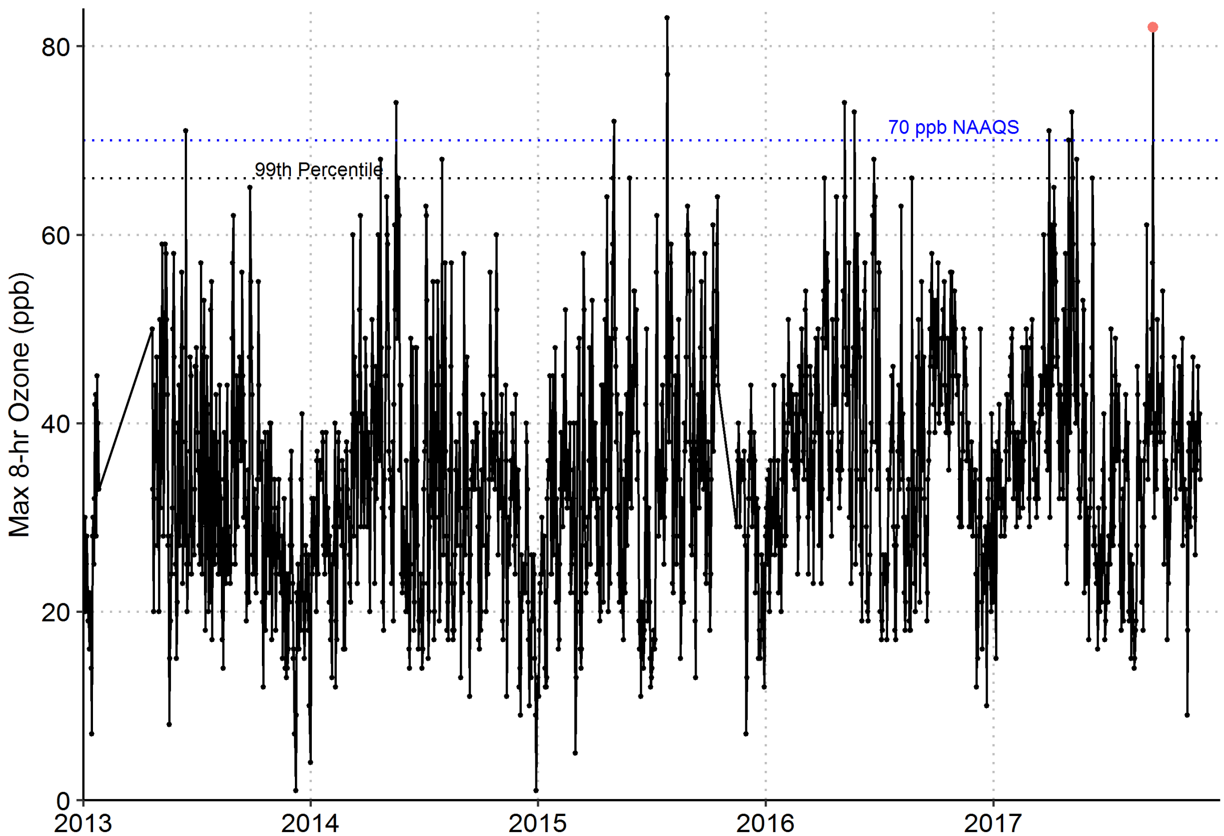

Figure A-14. Daily maximum 8-hr ozone concentrations at the Port Allen monitoring site (AQS ID 22-121-0001) from 2013 through 2017.

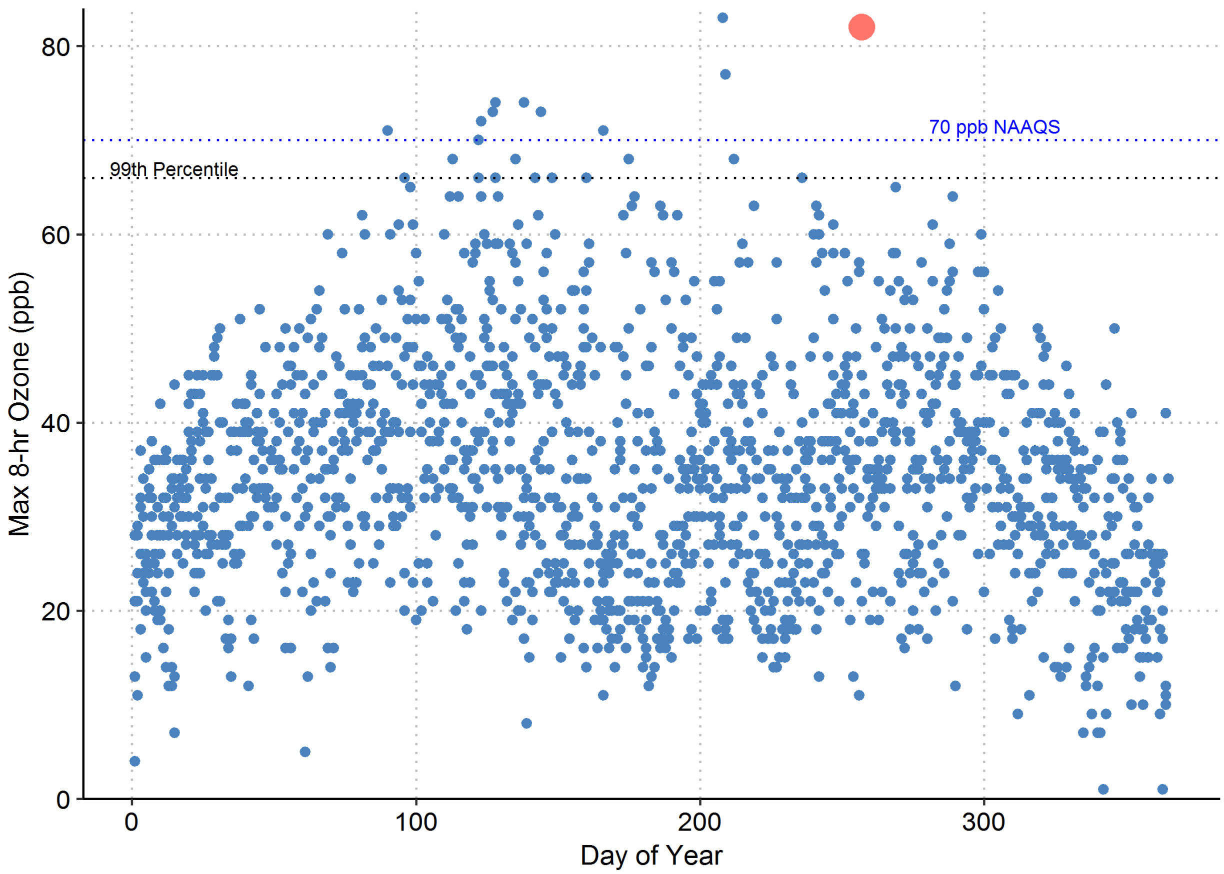

Figure A-15. Daily maximum 8-hr ozone concentrations at the Port Allen monitoring site (AQS ID 22-121-0001) from 2013 through 2017 by day of year.

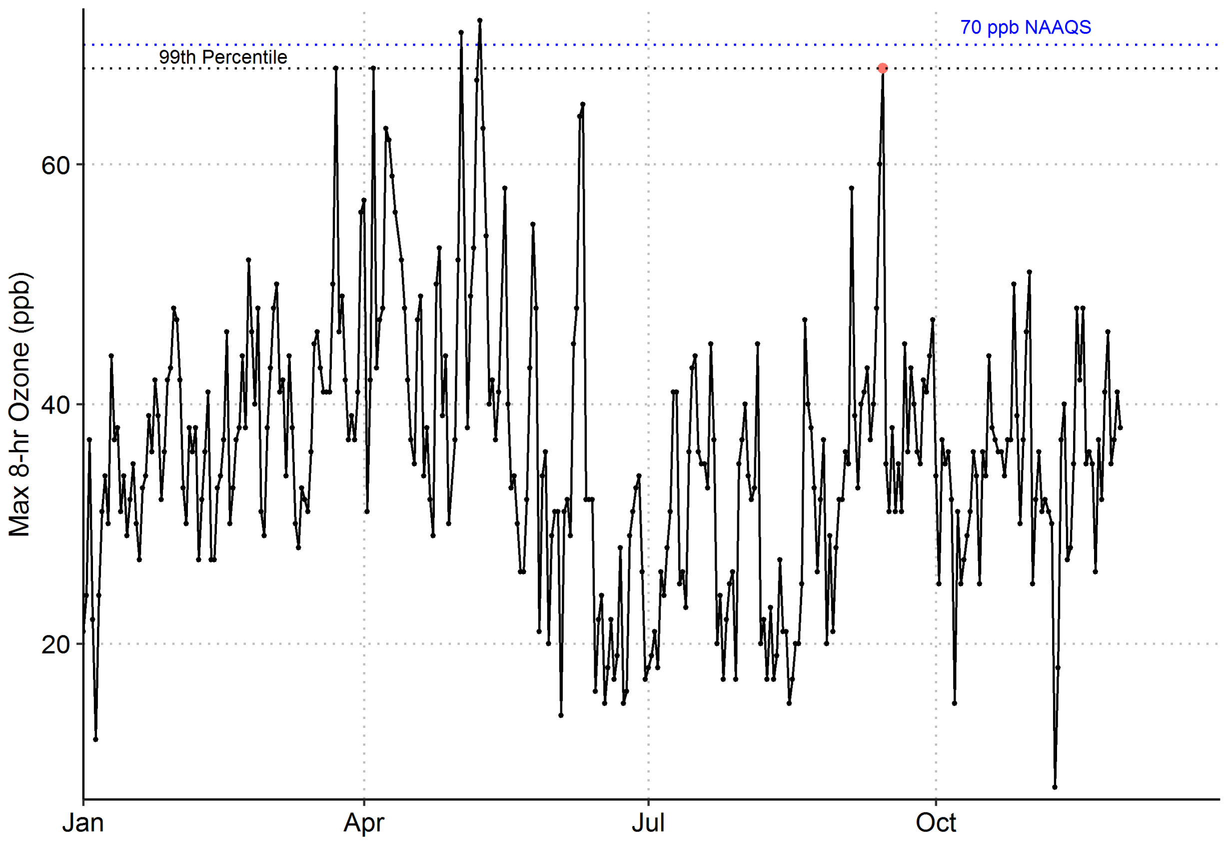

Figure A-16. Daily maximum 8-hr ozone concentrations at the New Roads monitoring site (AQS ID 22-077-0001) in 2017.

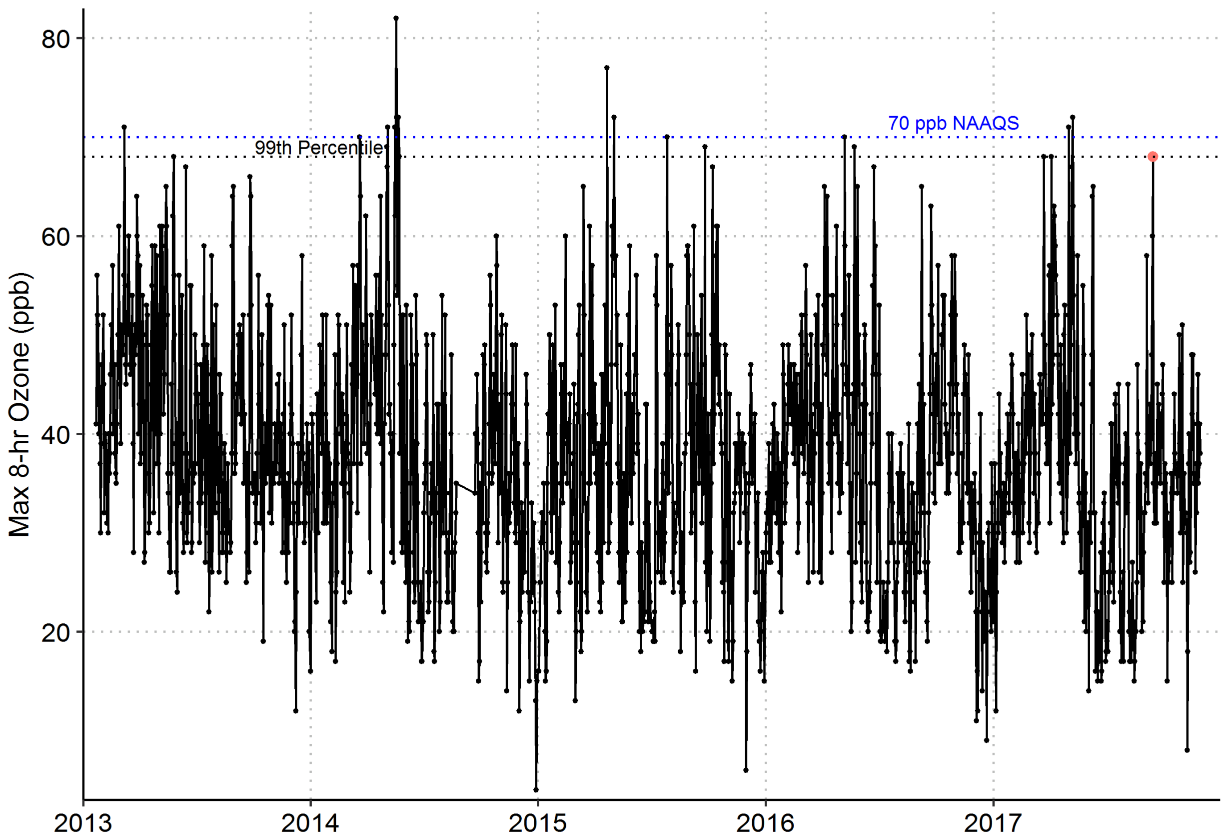

Figure A-17. Daily maximum 8-hr ozone concentrations at the New Roads monitoring site (AQS ID 22-077-0001) from 2013 through 2017.

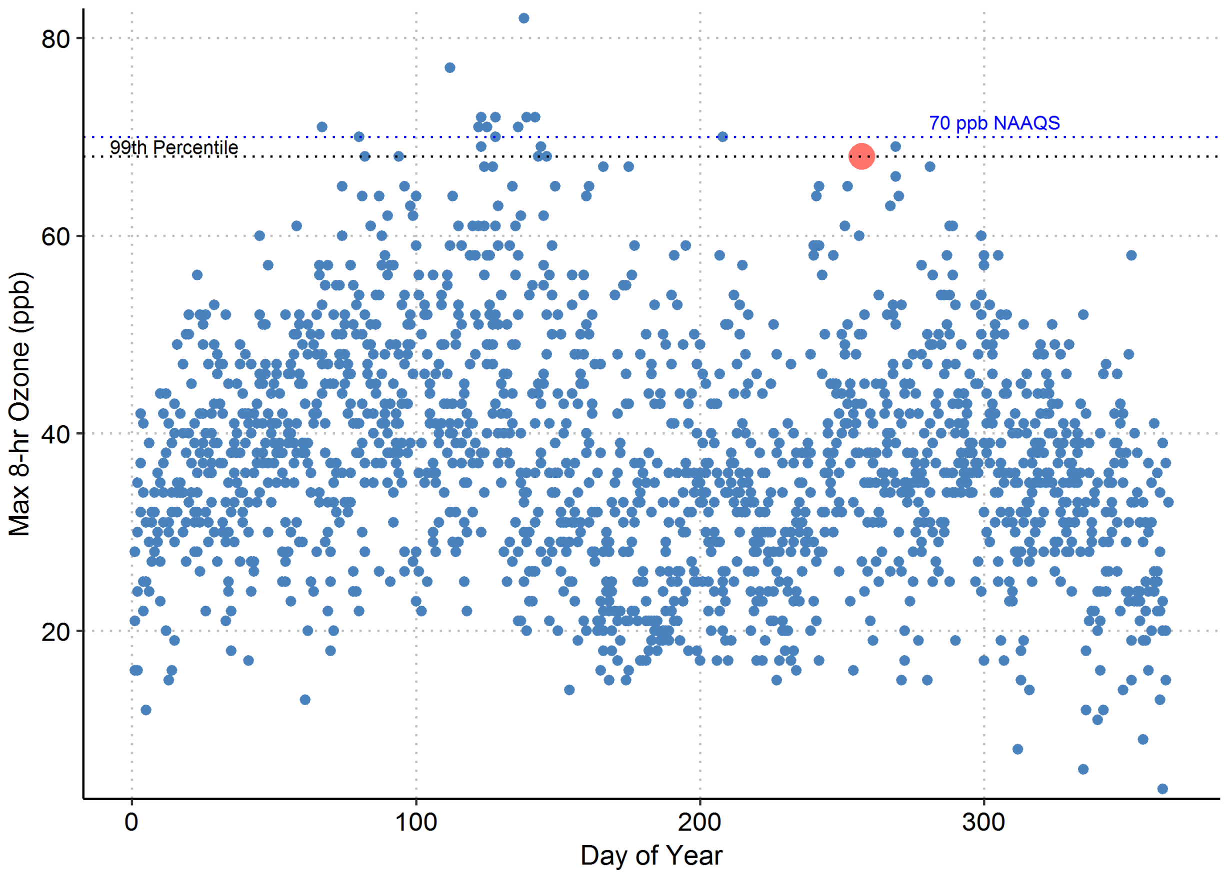

Figure A-18. Daily maximum 8-hr ozone concentrations at the New Roads monitoring site (AQS ID 22-077-0001) from 2013 through 2017 by day of year.

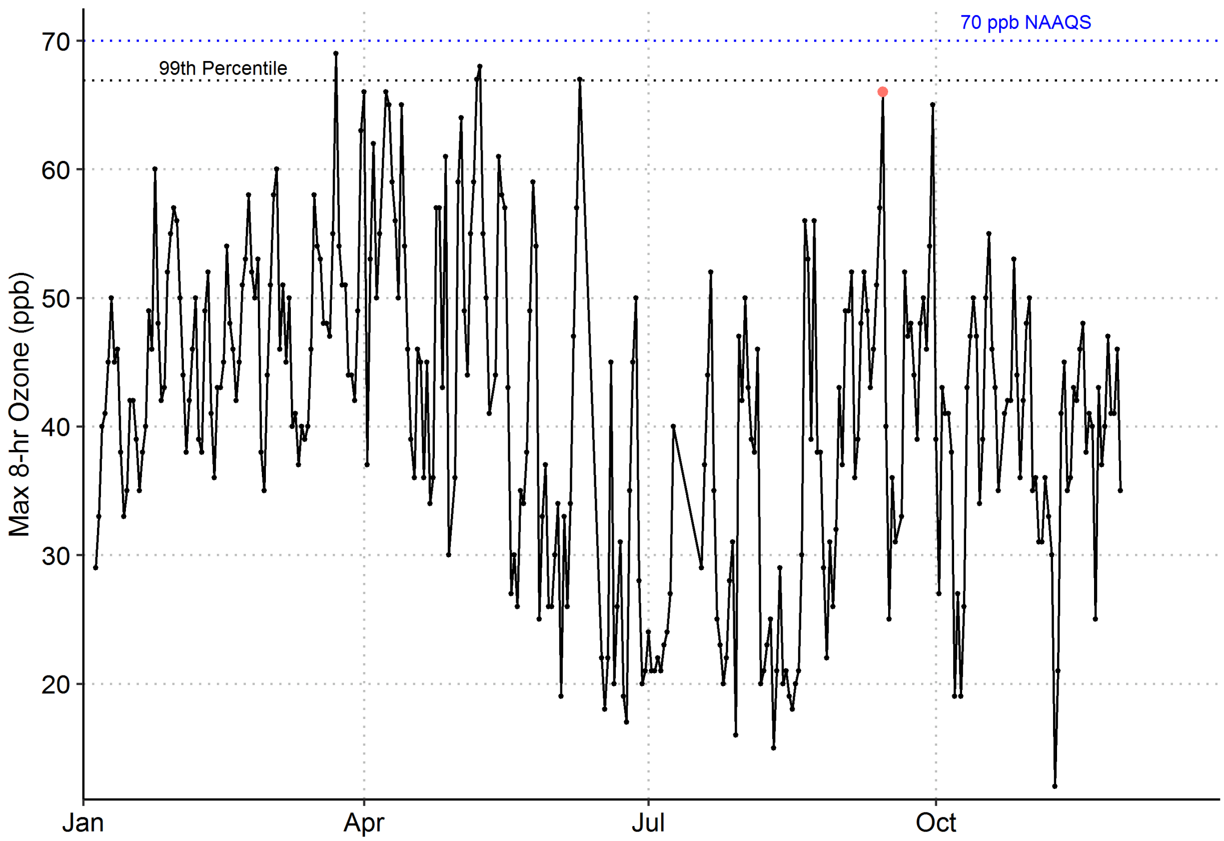

Figure A-19. Daily maximum 8-hr ozone concentrations at the Bayou Plaquemine monitoring site (AQS ID 22-047-0009) in 2017.

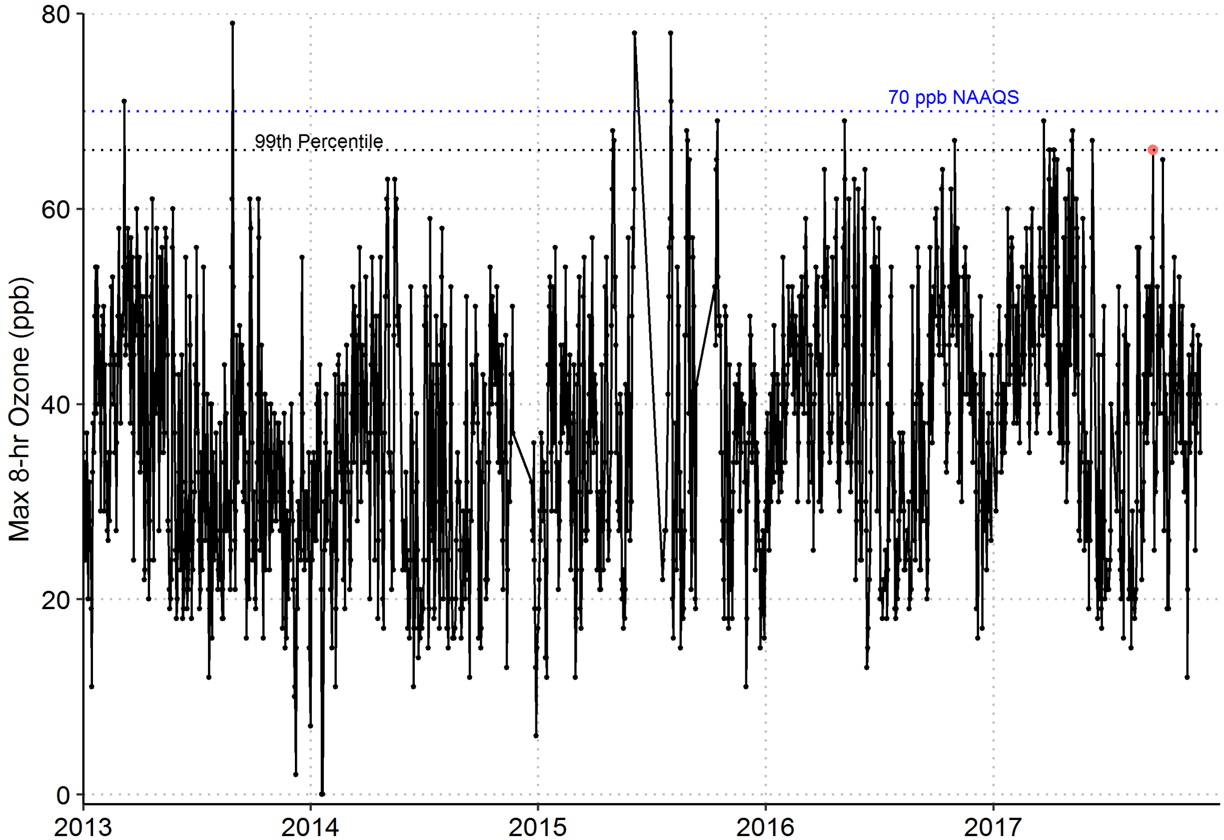

Figure A-20. Daily maximum 8-hr ozone concentrations at the Bayou Plaquemine monitoring site (AQS ID 22-047-0009) from 2013 through 2017.

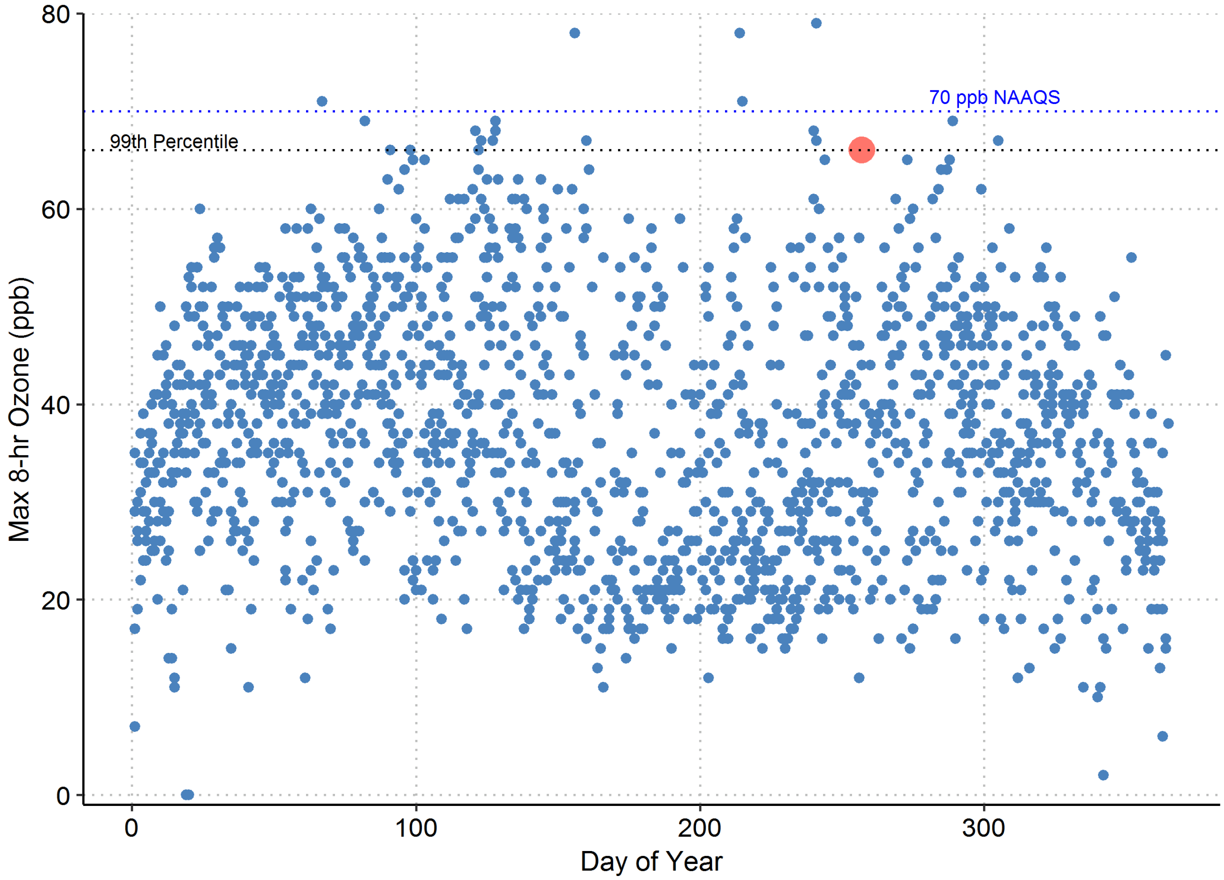

Figure A-21. Daily maximum 8-hr ozone concentrations at the Bayou Plaquemine monitoring site (AQS ID 22-047-0009) from 2013 through 2017 by day of year.

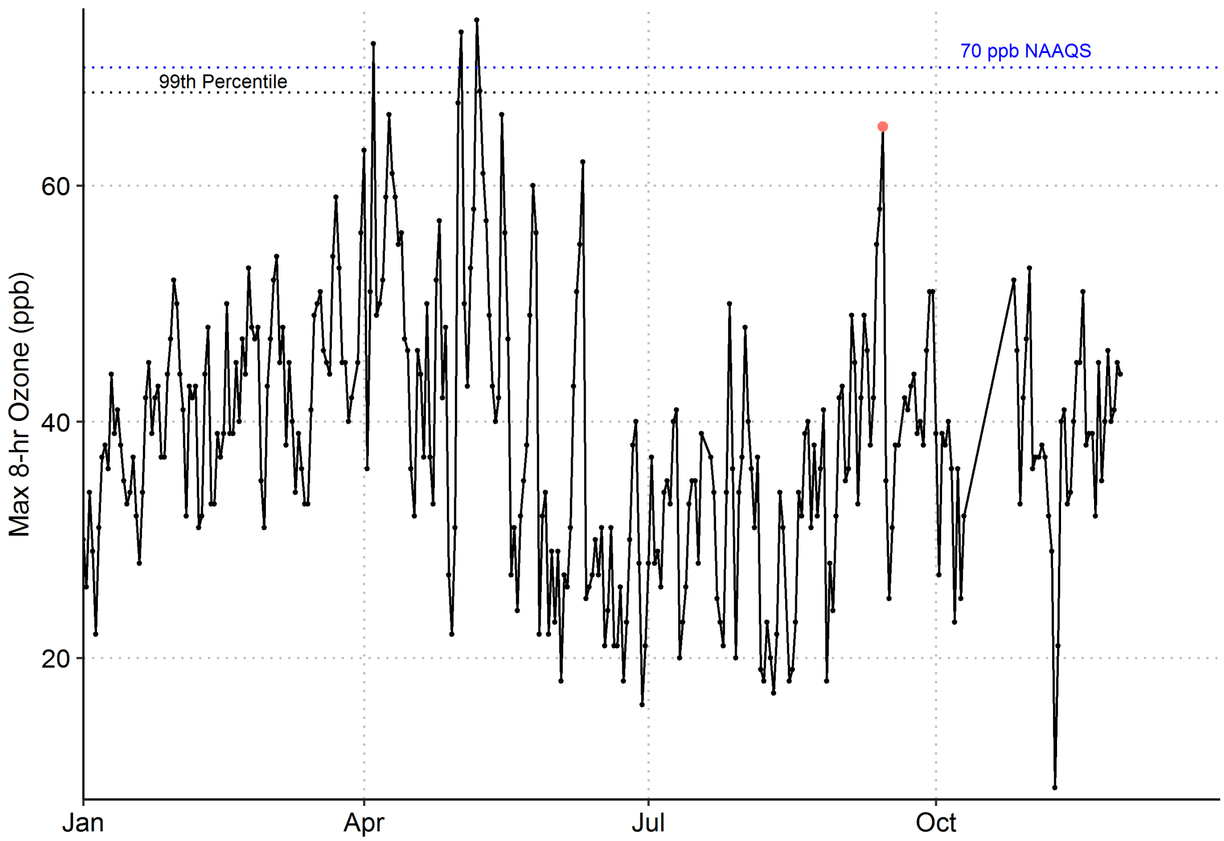

Figure A-22. Daily maximum 8-hr ozone concentrations at the French Settlement monitoring site (AQS ID 22-063-0002) in 2017.

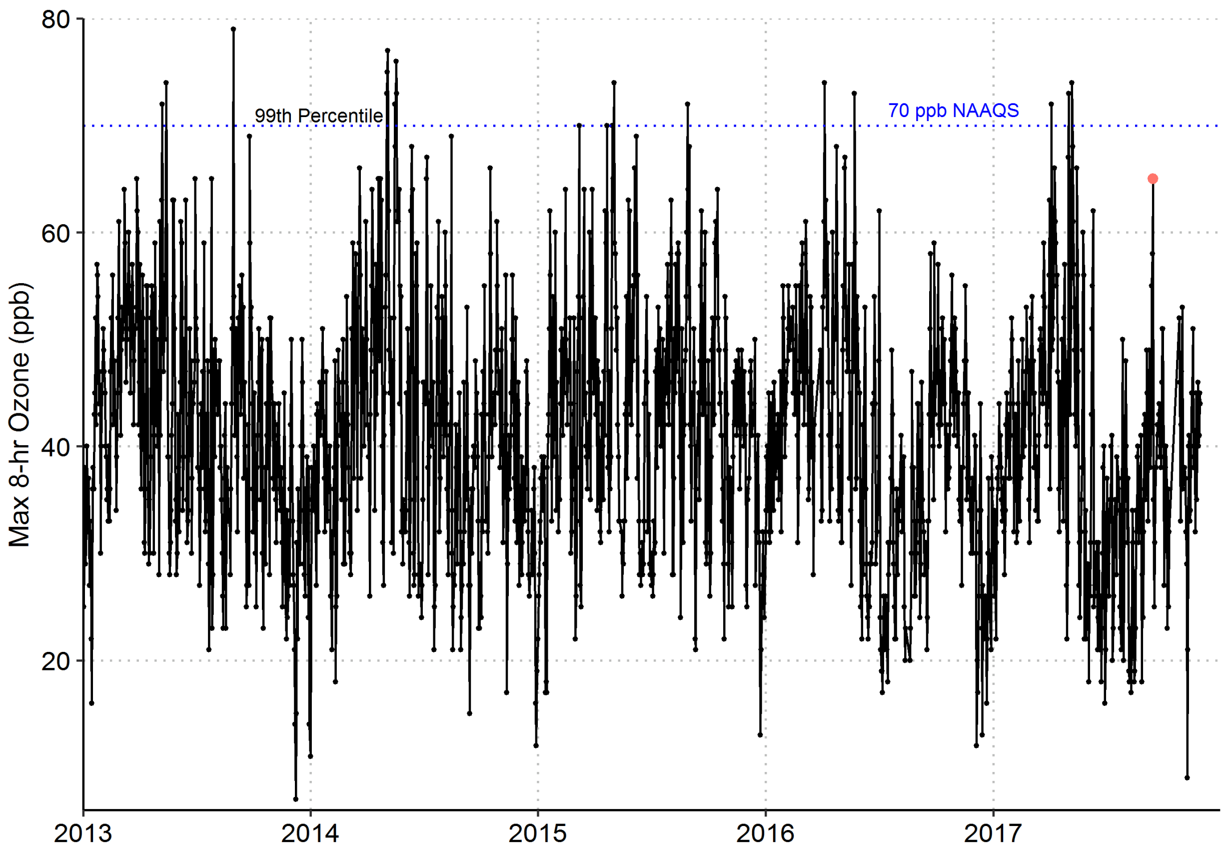

Figure A-23. Daily maximum 8-hr ozone concentrations at the French Settlement monitoring site (AQS ID 22-063-0002) from 2013 through 2017.

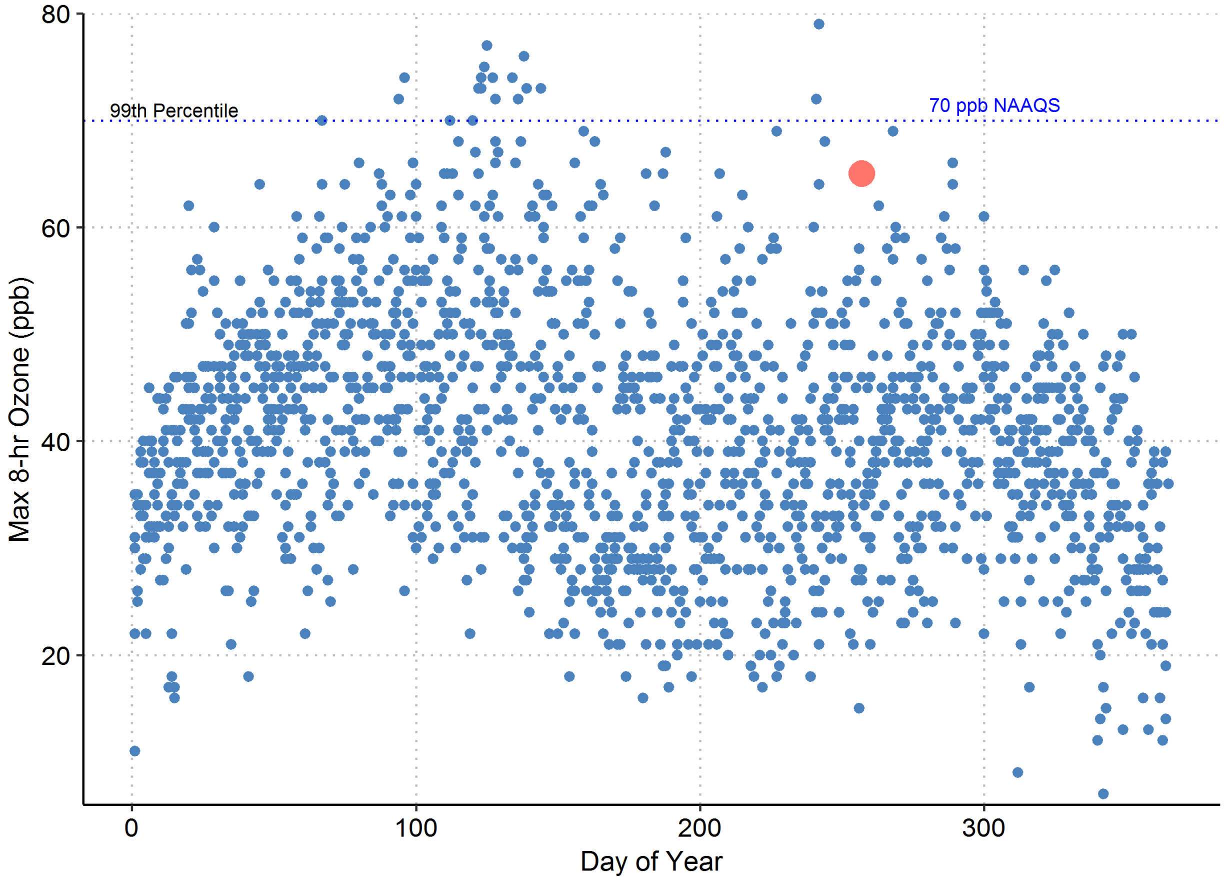

Figure A-24. Daily maximum 8-hr ozone concentrations at the French Settlement monitoring site (AQS ID 22-063-0002) from 2013 through 2017 by day of year.

Appendix B. Additional Supporting Measurements

Additional measurements collected at the Capitol monitoring site (AQS ID 22-033-0009) are shown in the following figures for September 1 through September 18, 2017. Measurements include speciated volatile organic compounds (VOCs) from the Photochemical Assessment Monitoring Stations (PAMS), NO, NO_x, NO_y, and CO. PAMS measurements track ozone and ozone precursors. Not all measurements are indicators of smoke impacts.

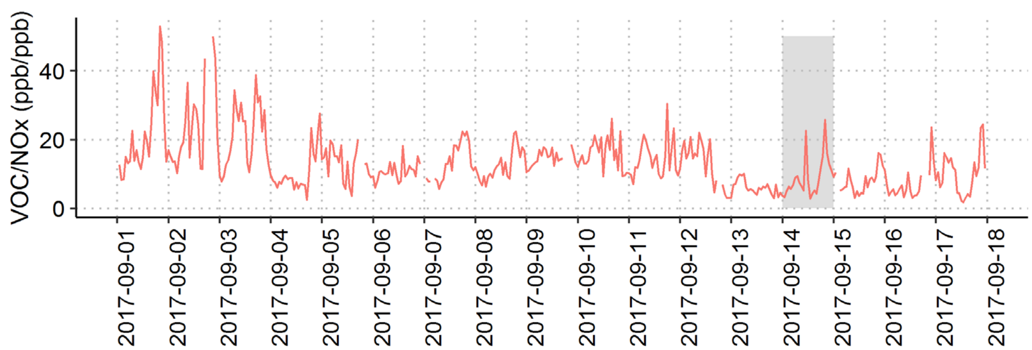

Figure B-1. VOC/NO_x ratio measured at the Capitol site between September 1 and 18, 2017.

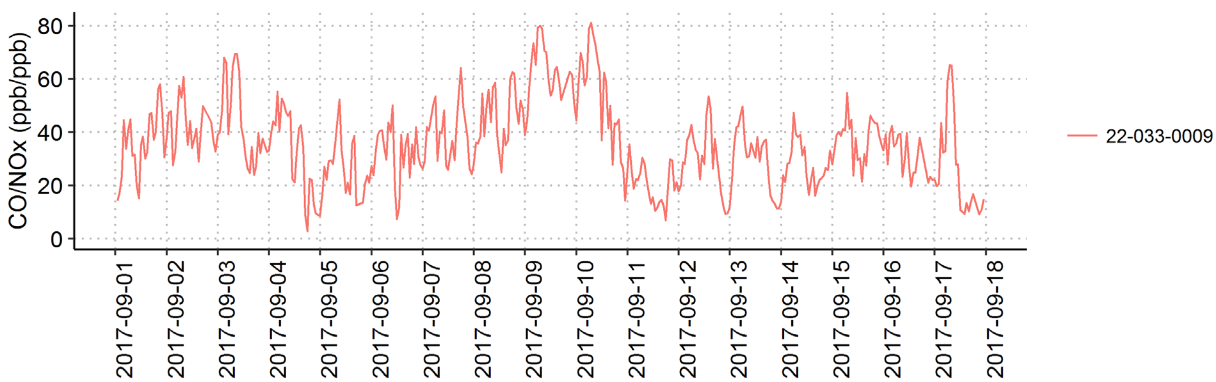

Figure B-2. CO/NO_x ratio measured at the Capitol site between September 1 and 18, 2017.

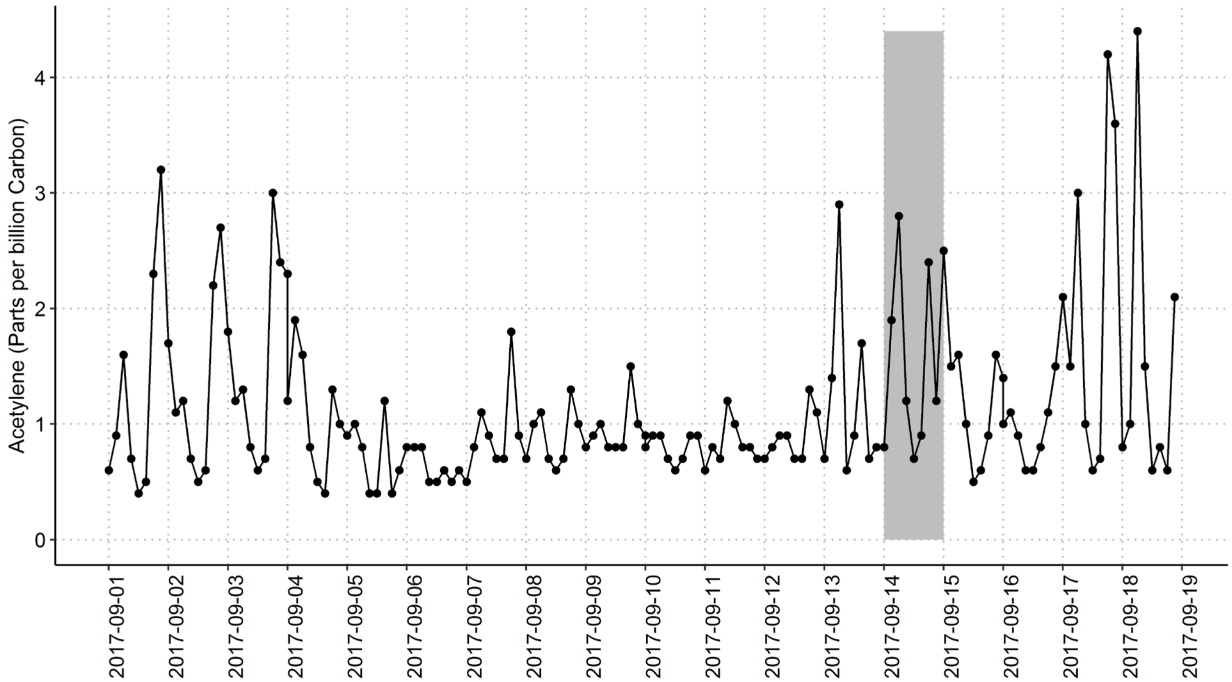

Figure B-3. Acetylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

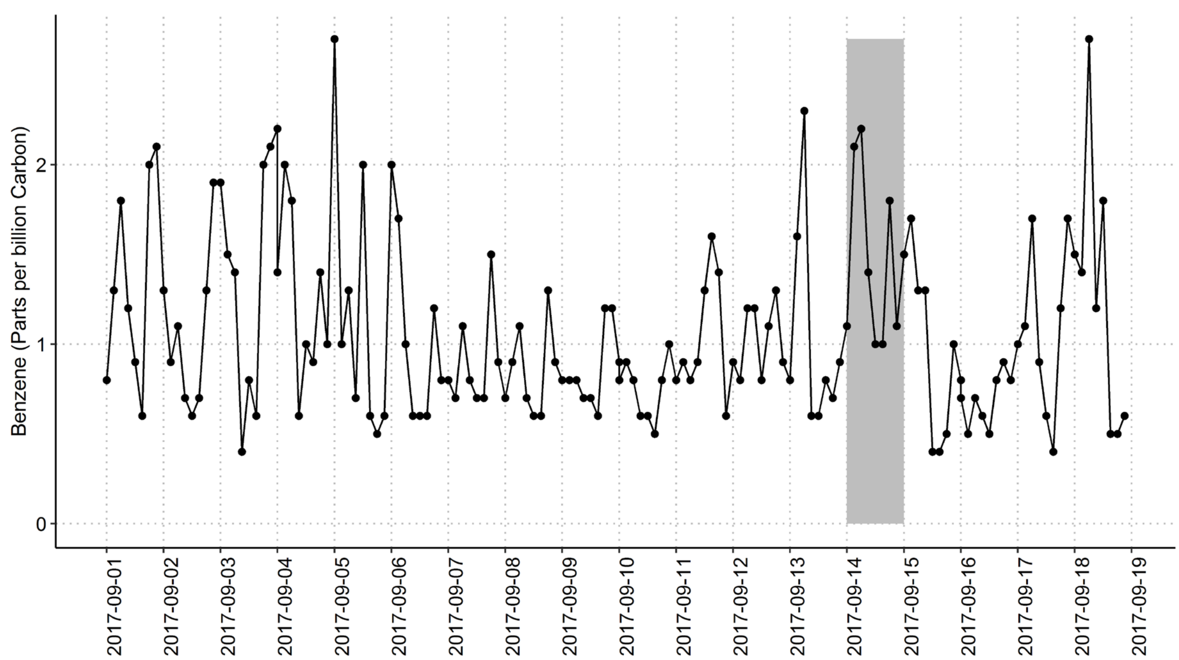

Figure B-4. Benzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

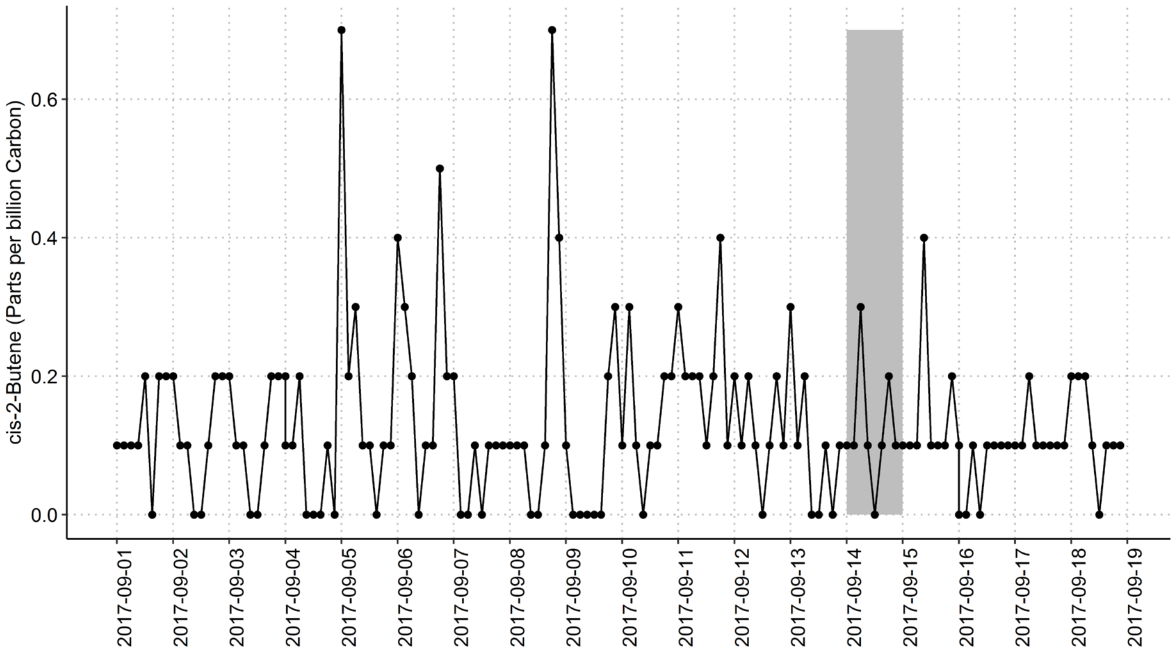

Figure B-5. cis-2-Butene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

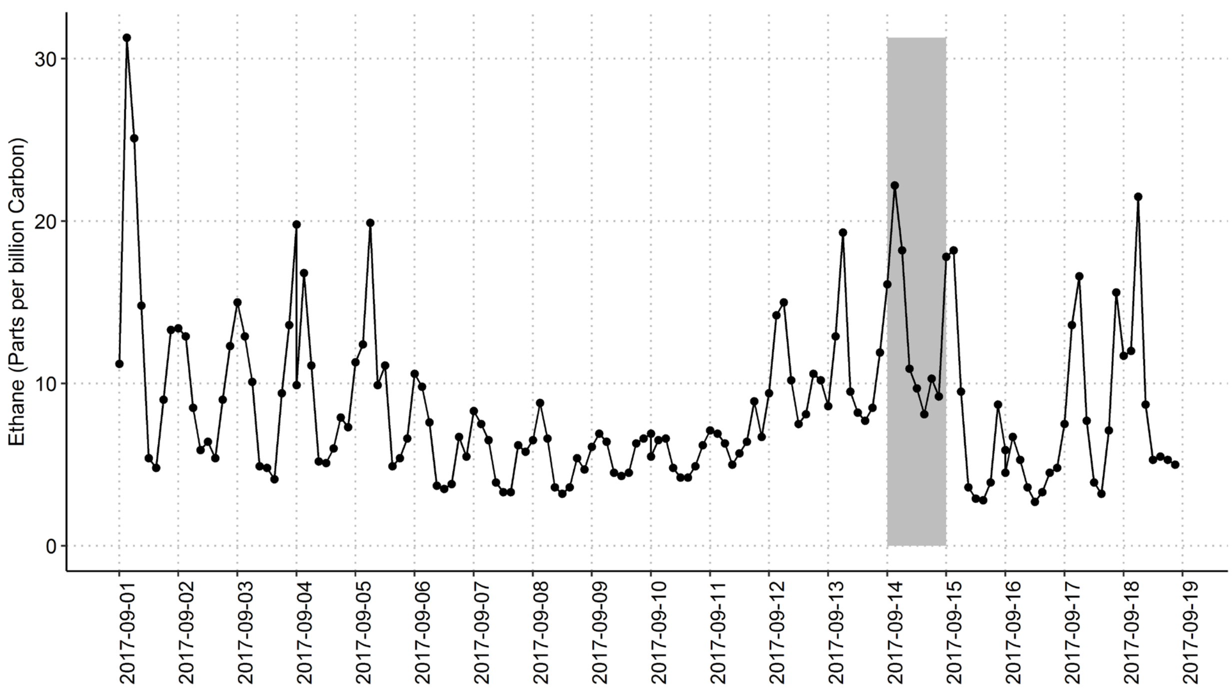

Figure B-6. Ethane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

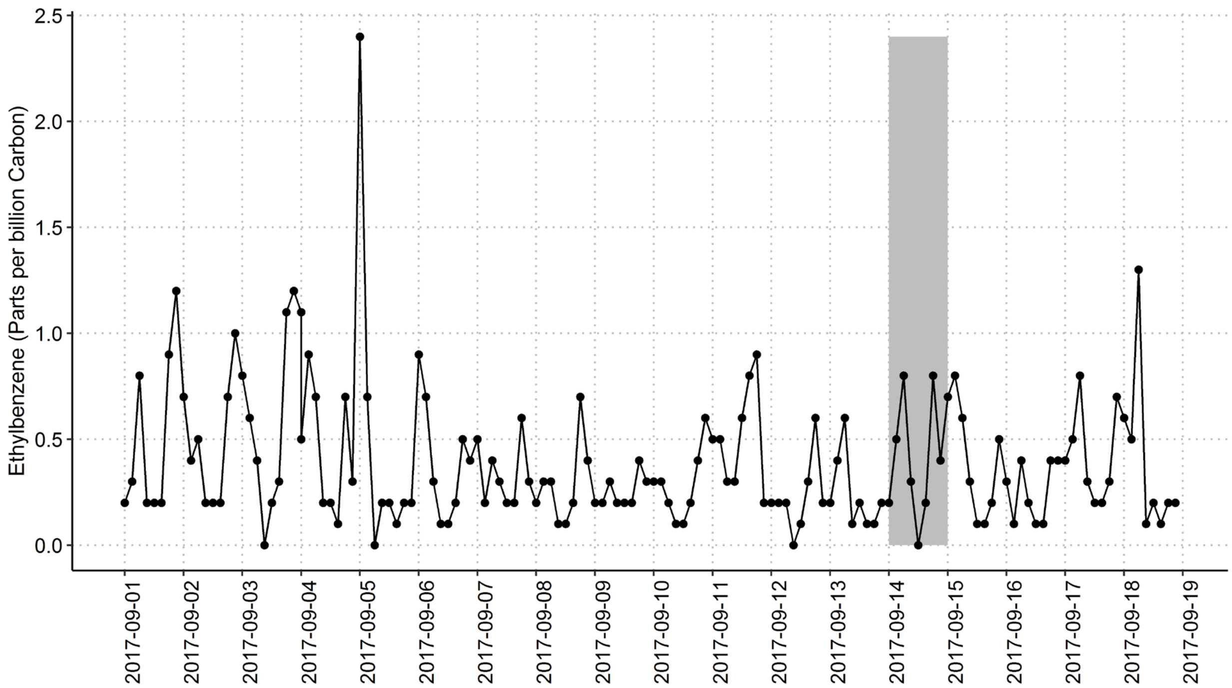

Figure B-7. Ethylbenzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

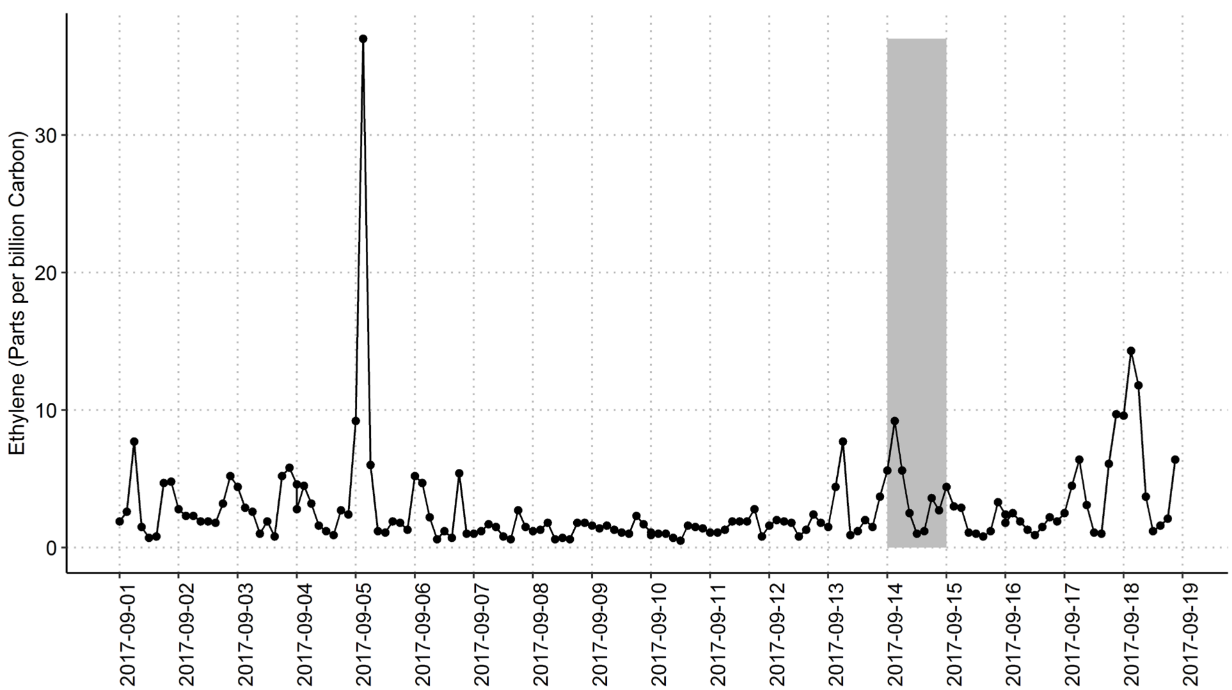

Figure B-8. Ethylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

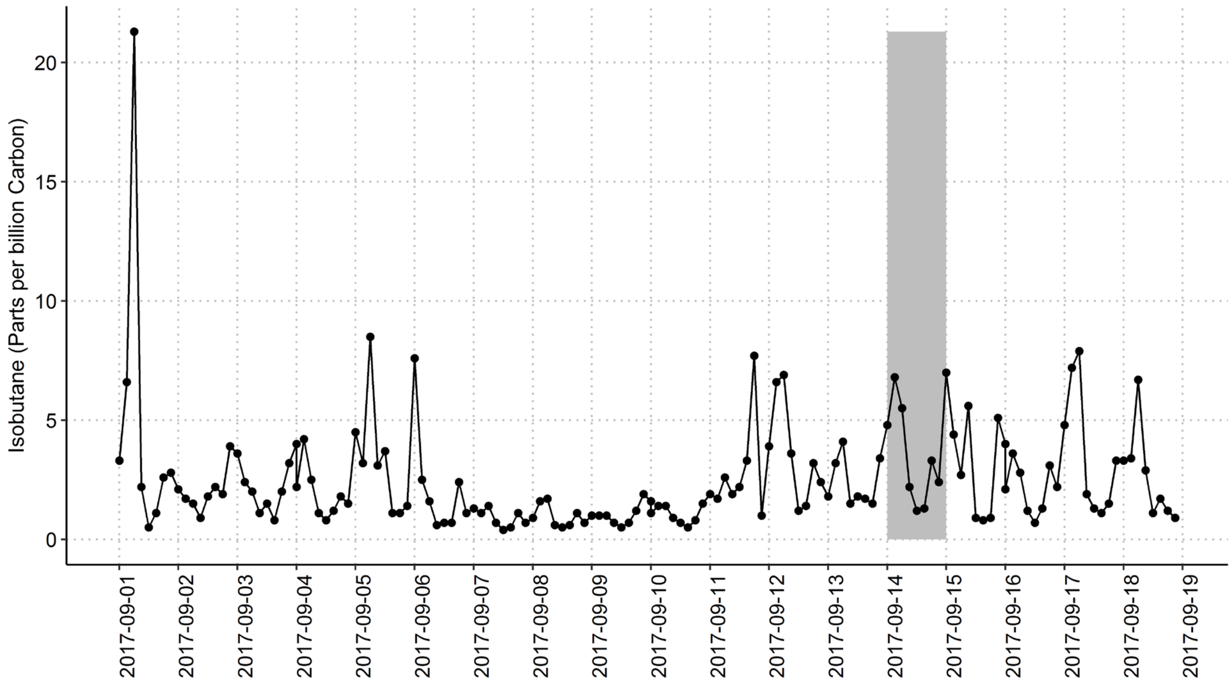

Figure B-9. Isobutane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

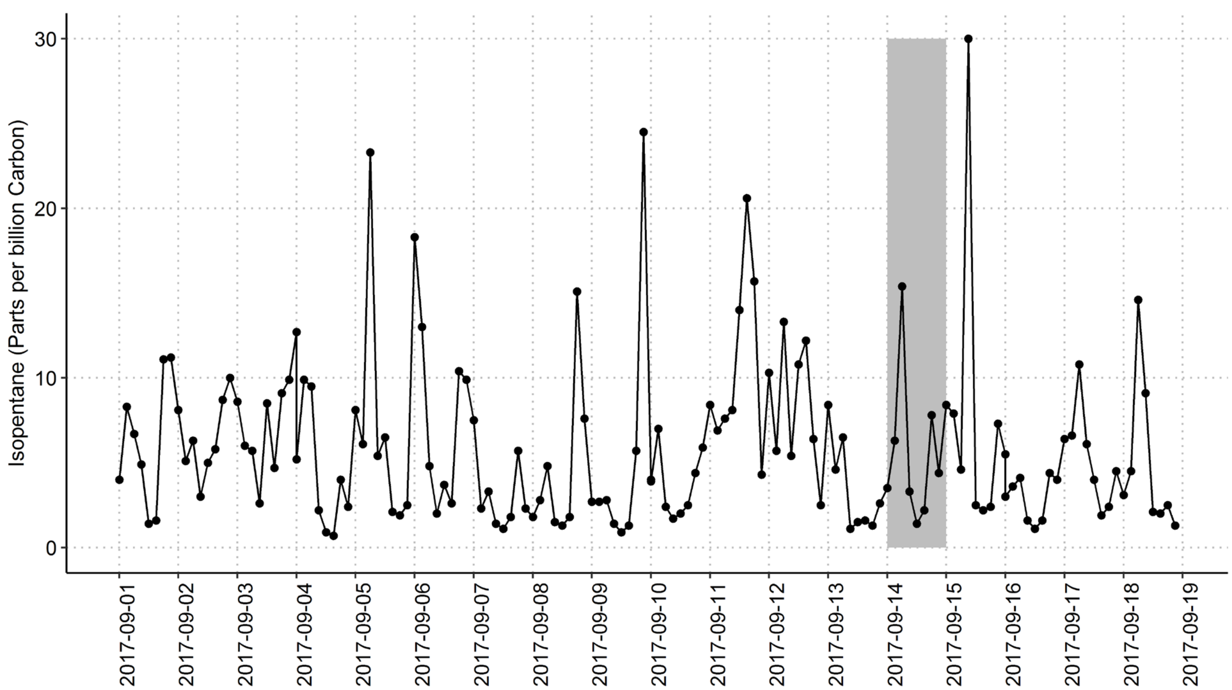

Figure B-10. Isopentane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

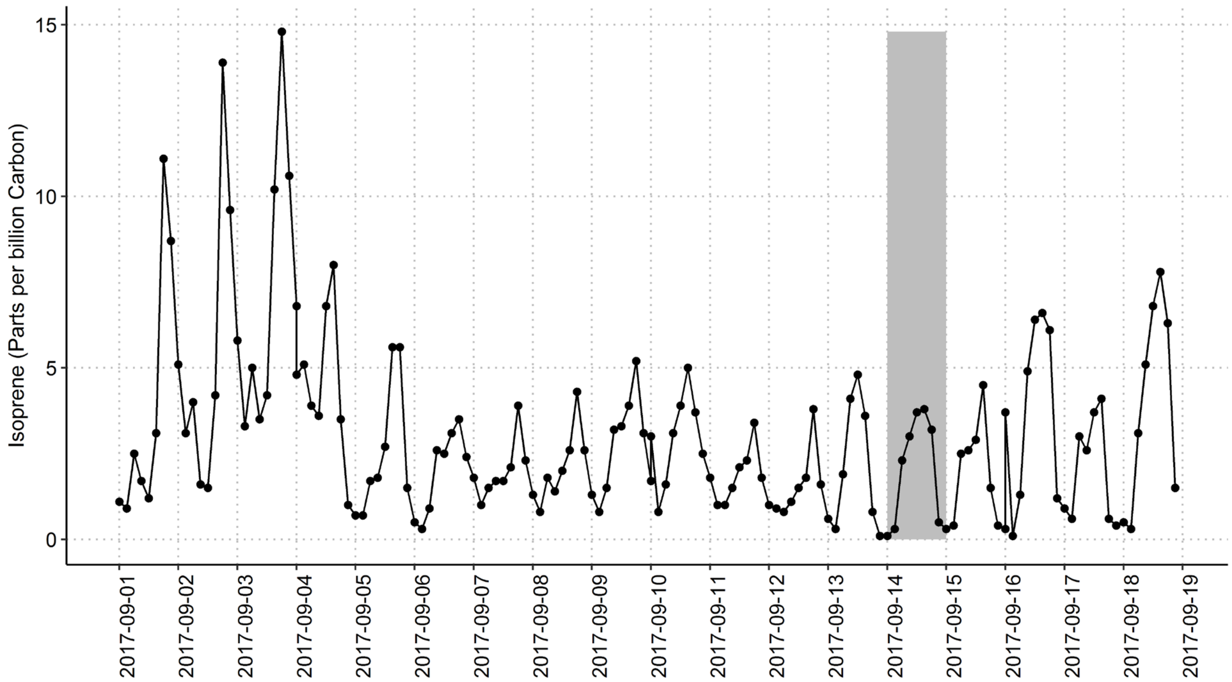

Figure B-11. Isoprene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

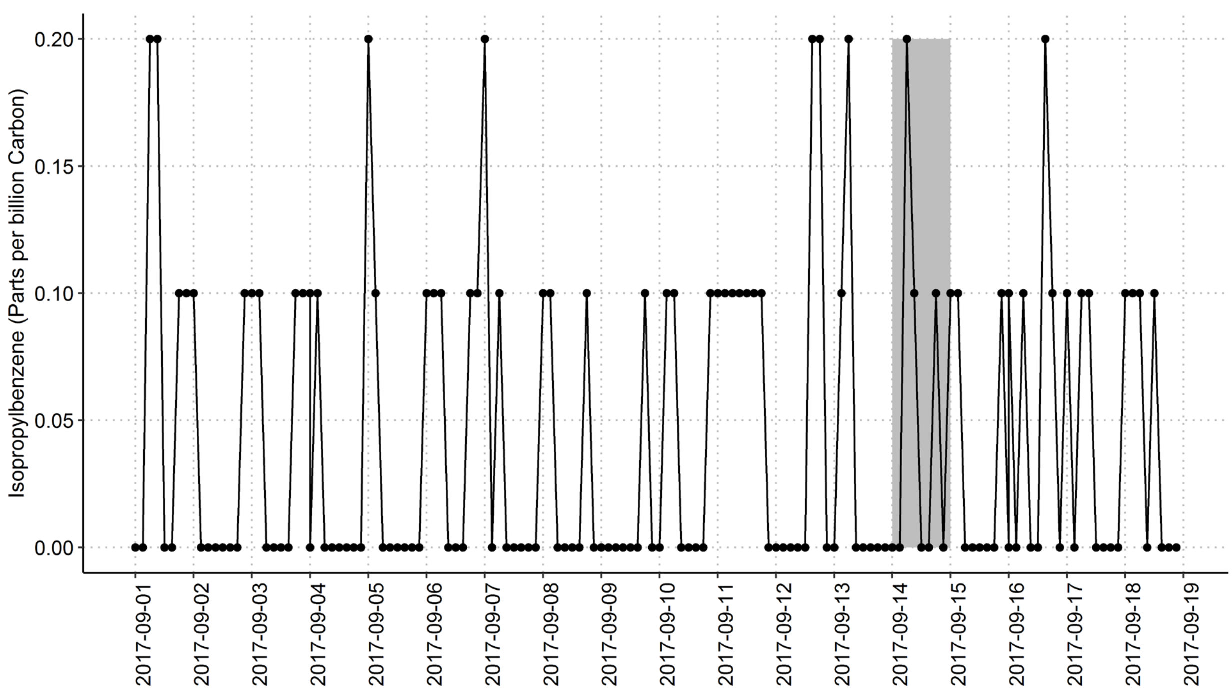

Figure B-12. Isopropylbenzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

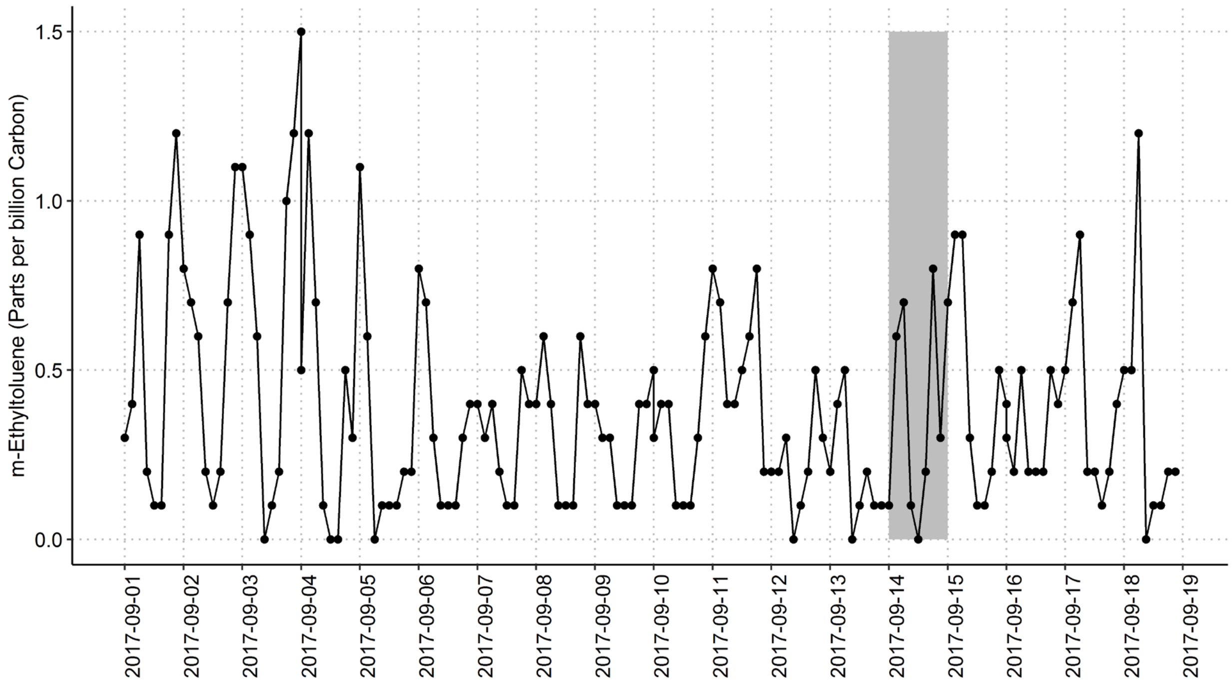

Figure B-13. m-Ethyltoluene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

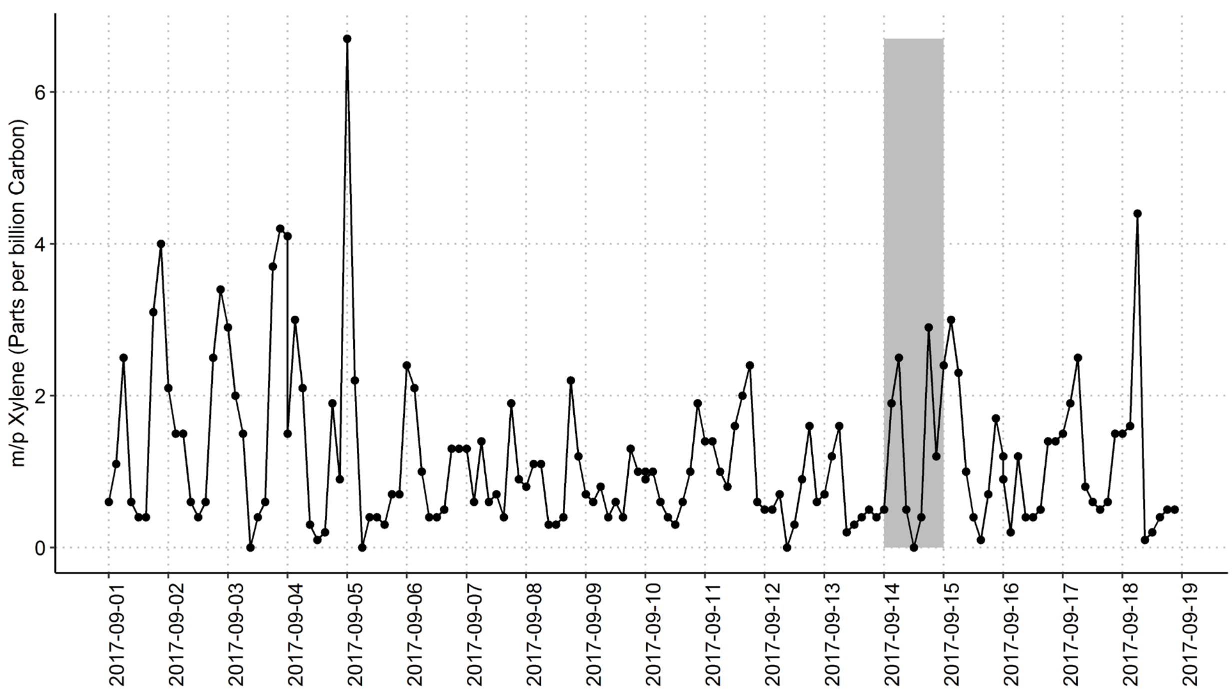

Figure B-14. m/p Xylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

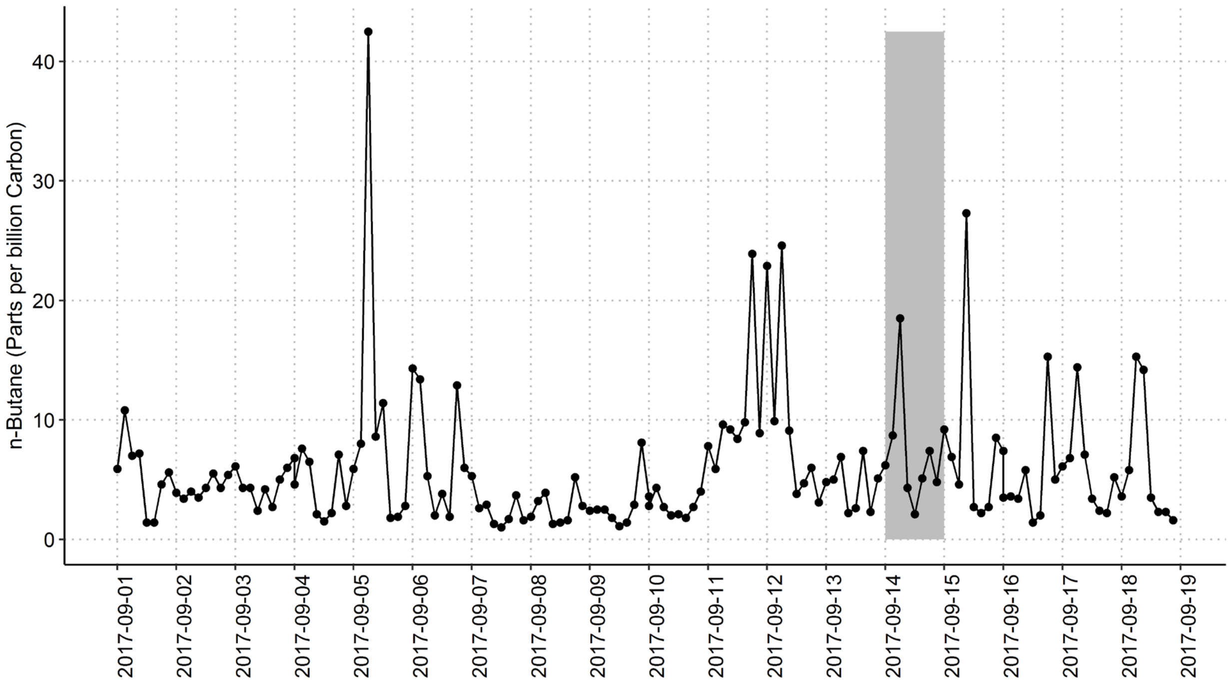

Figure B-15. n-Butane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

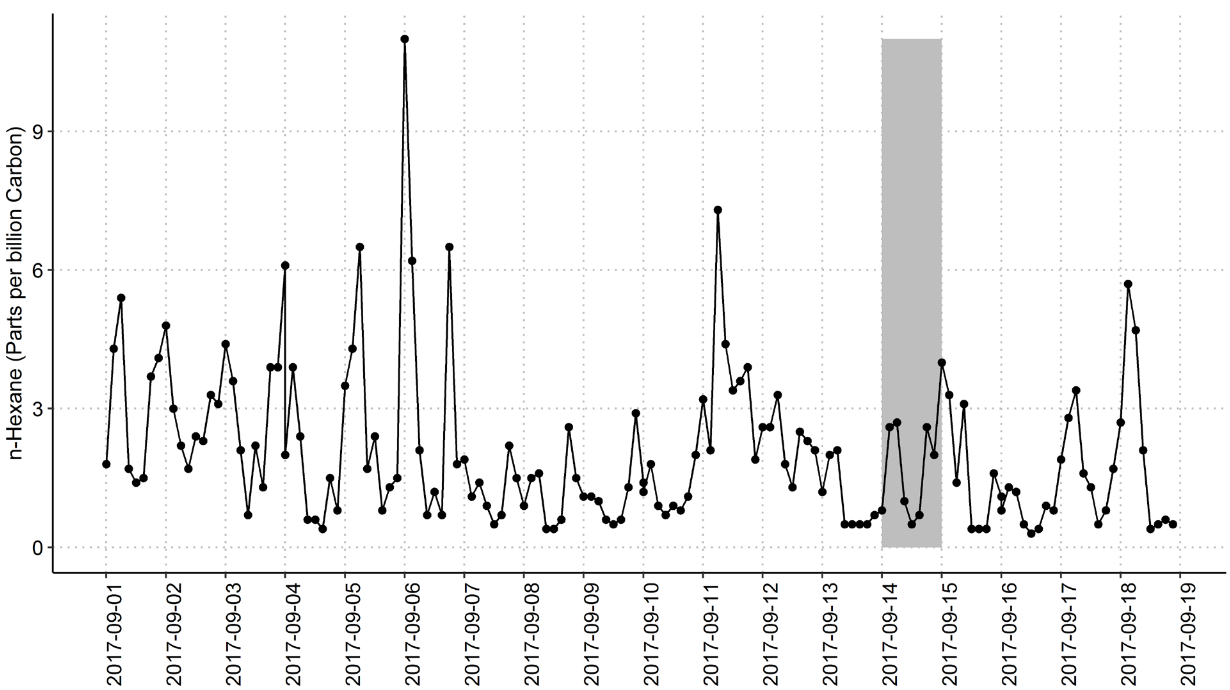

Figure B-16. n-Hexane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

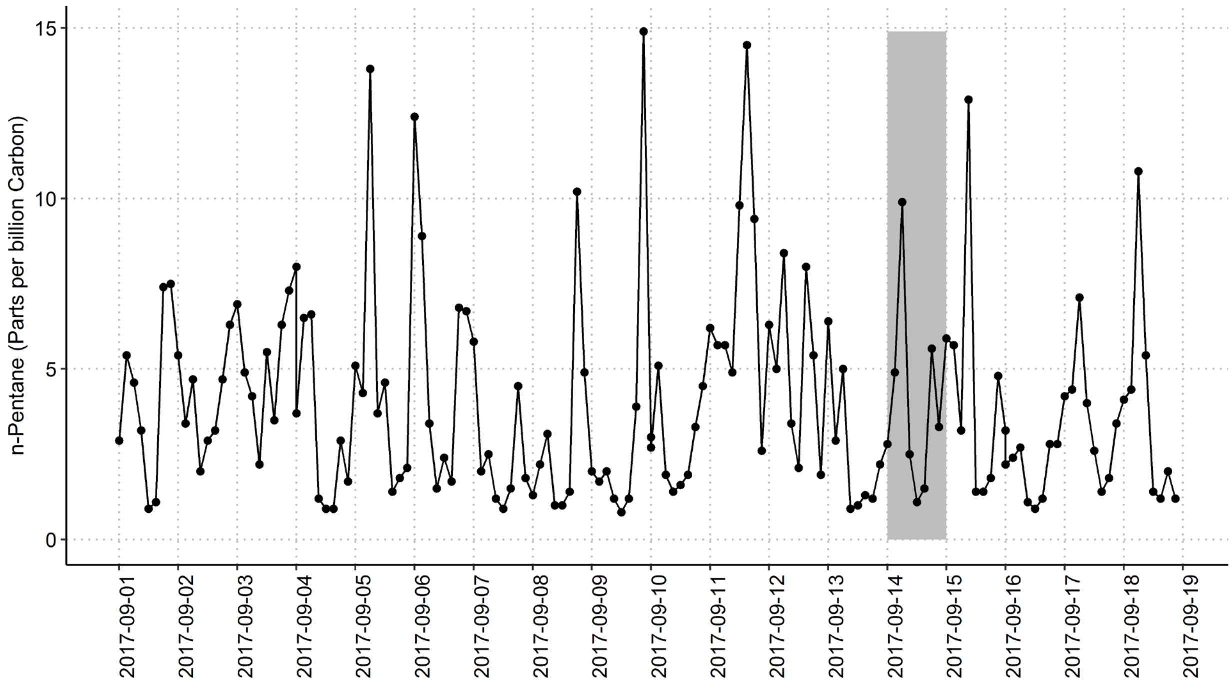

Figure B-17. n-Pentane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

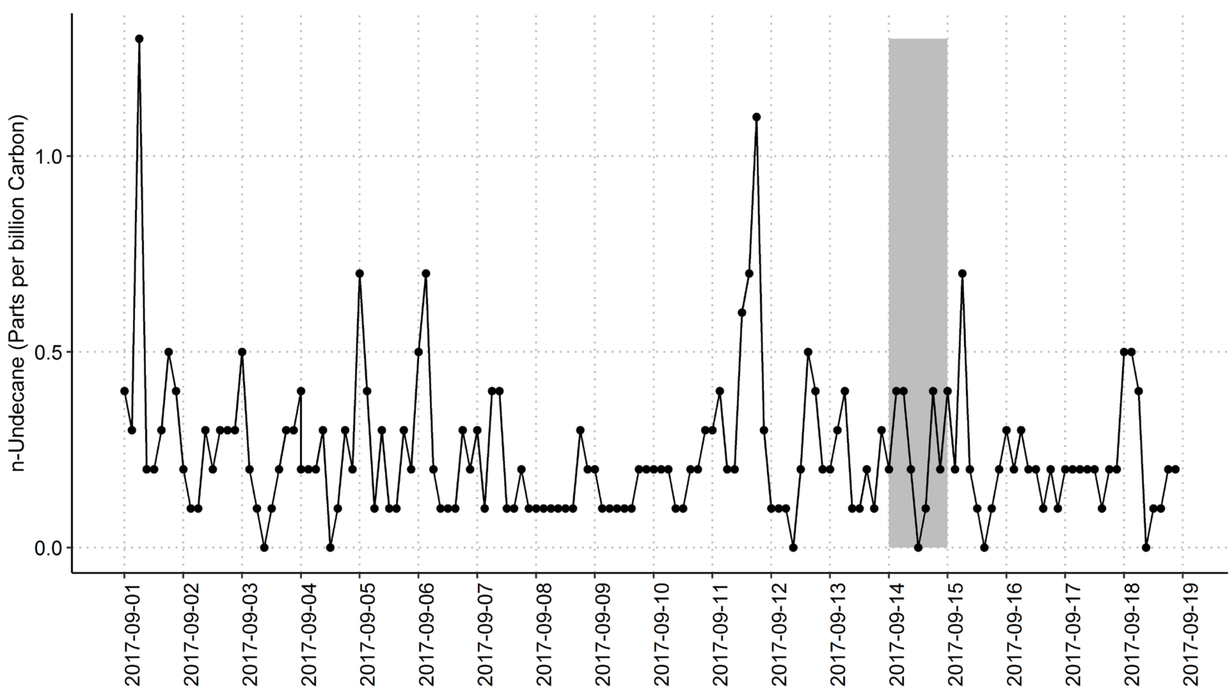

Figure B-18. n-Undecane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

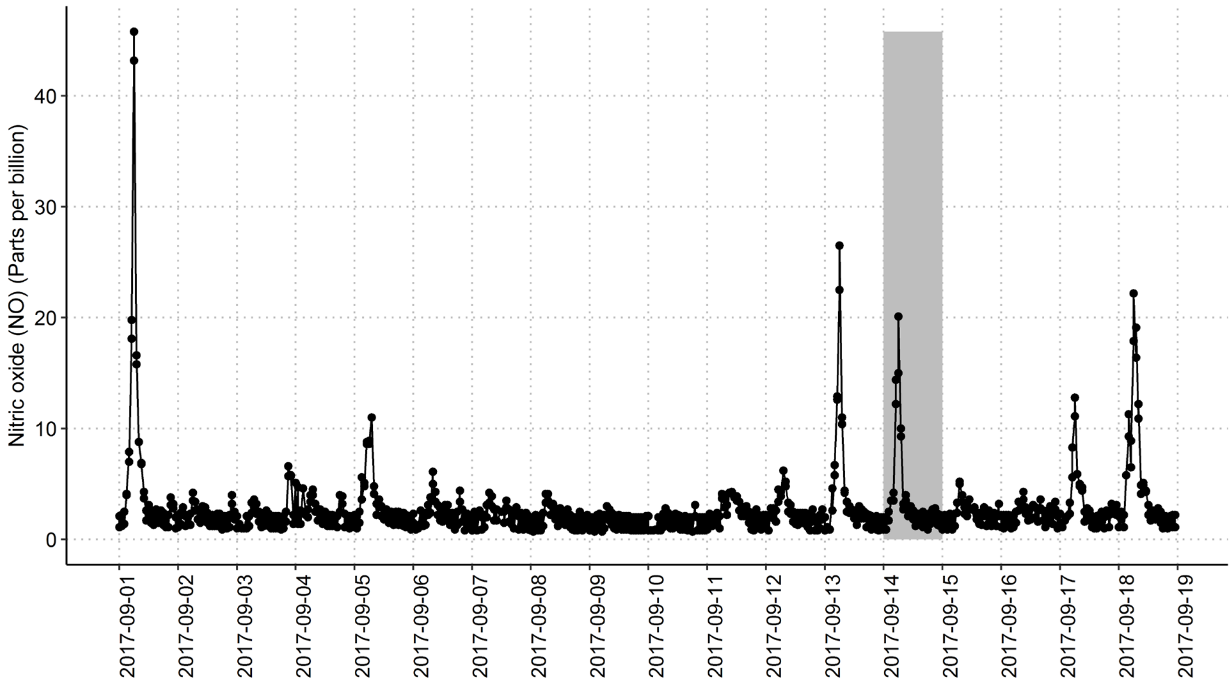

Figure B-19. Nitric oxide measurements at the Capitol monitoring site from September 1 through September 18, 2017.

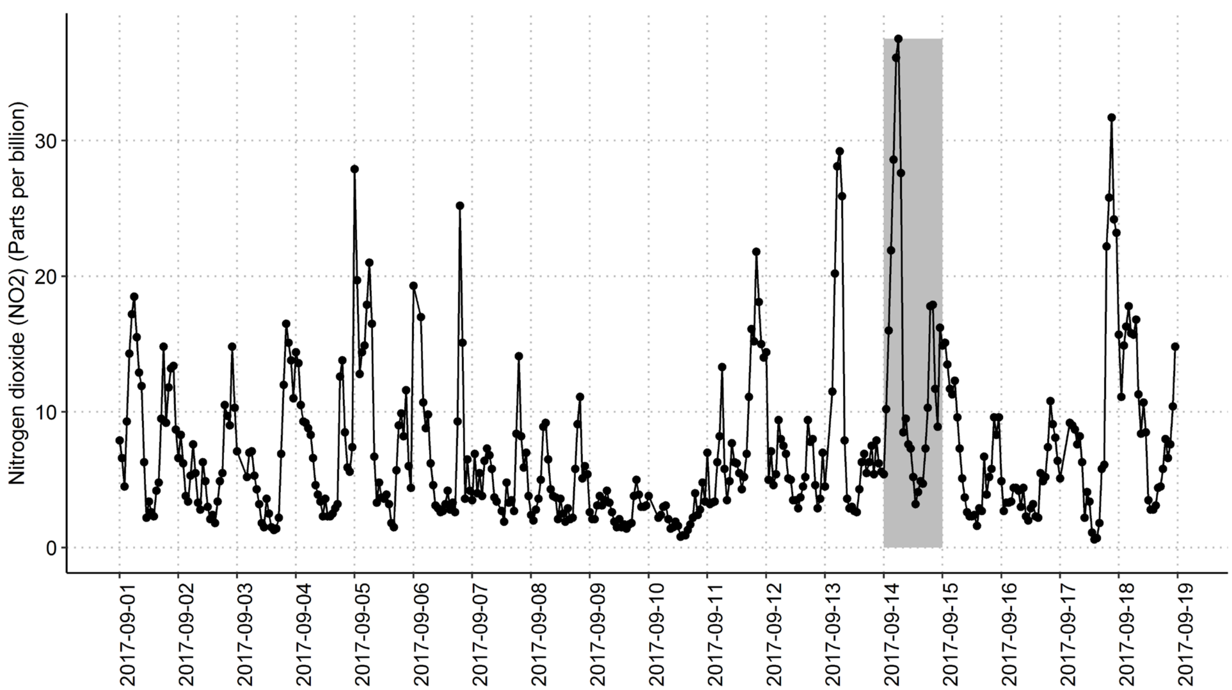

Figure B-20. Nitrogen dioxide measurements at the Capitol monitoring site from September 1 through September 18, 2017.

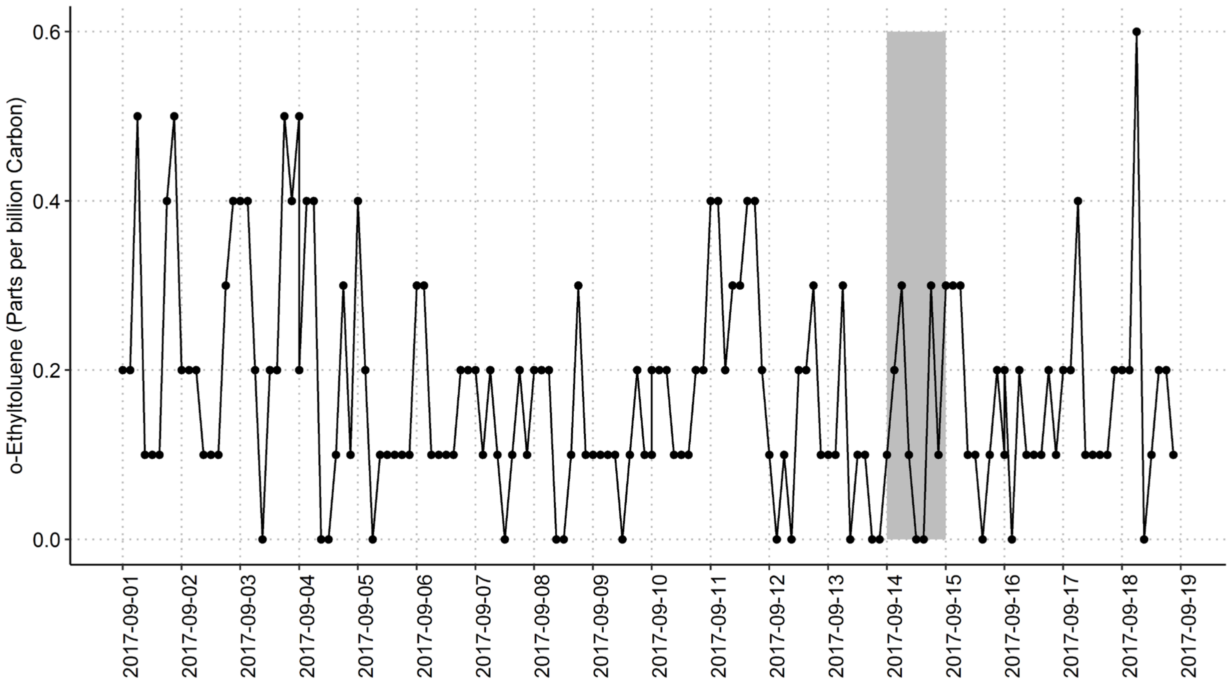

Figure B-21. o-Ethyltoluene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

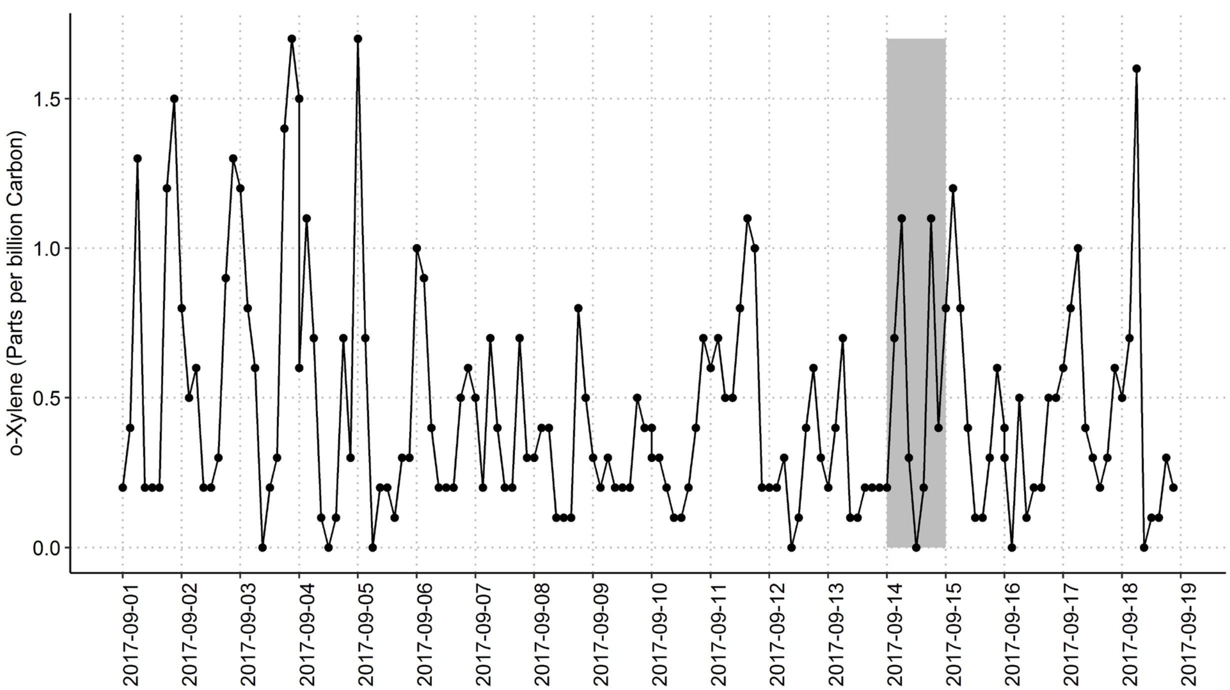

Figure B-22. o-Xylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

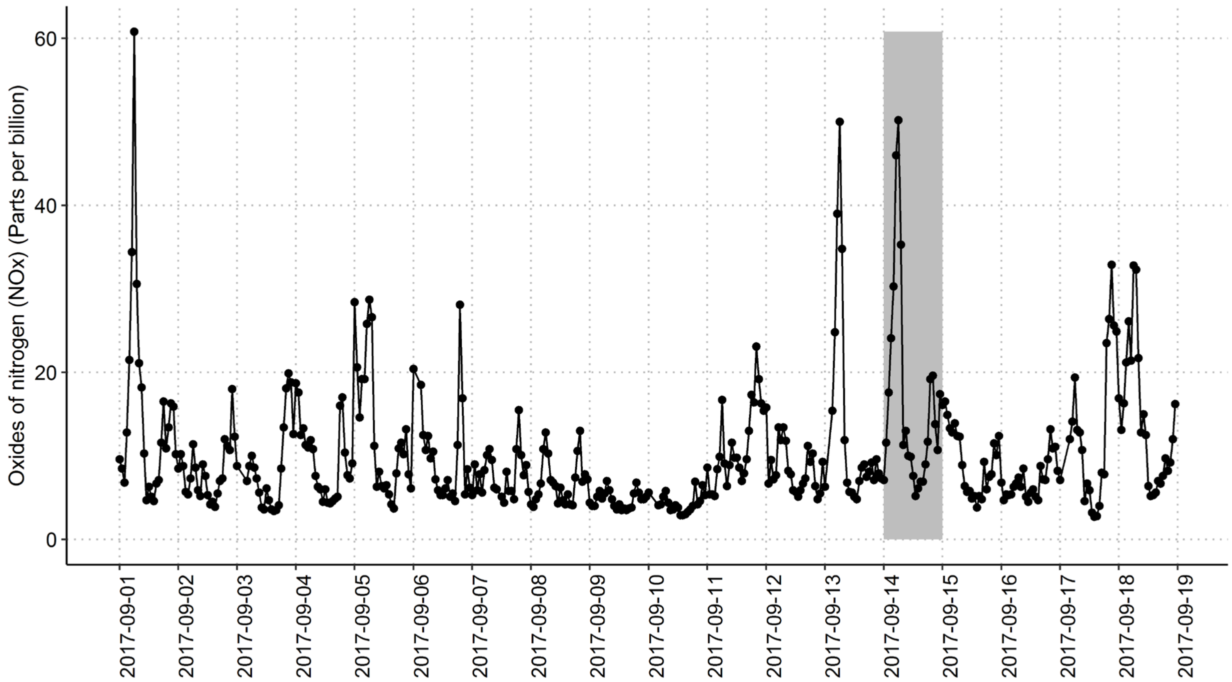

Figure B-23. Oxides of nitrogen (NO_x) measurements at the Capitol monitoring site from September 1 through September 18, 2017.

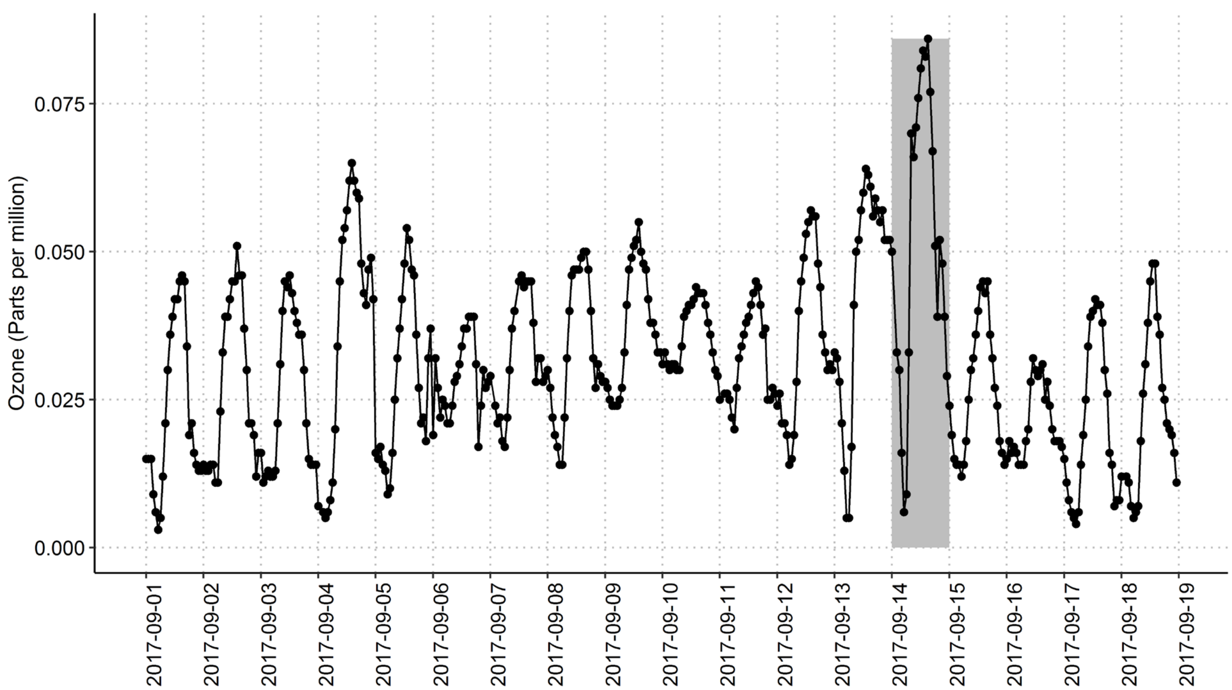

Figure B-24. Ozone measurements at the Capitol monitoring site from September 1 through September 18, 2017.

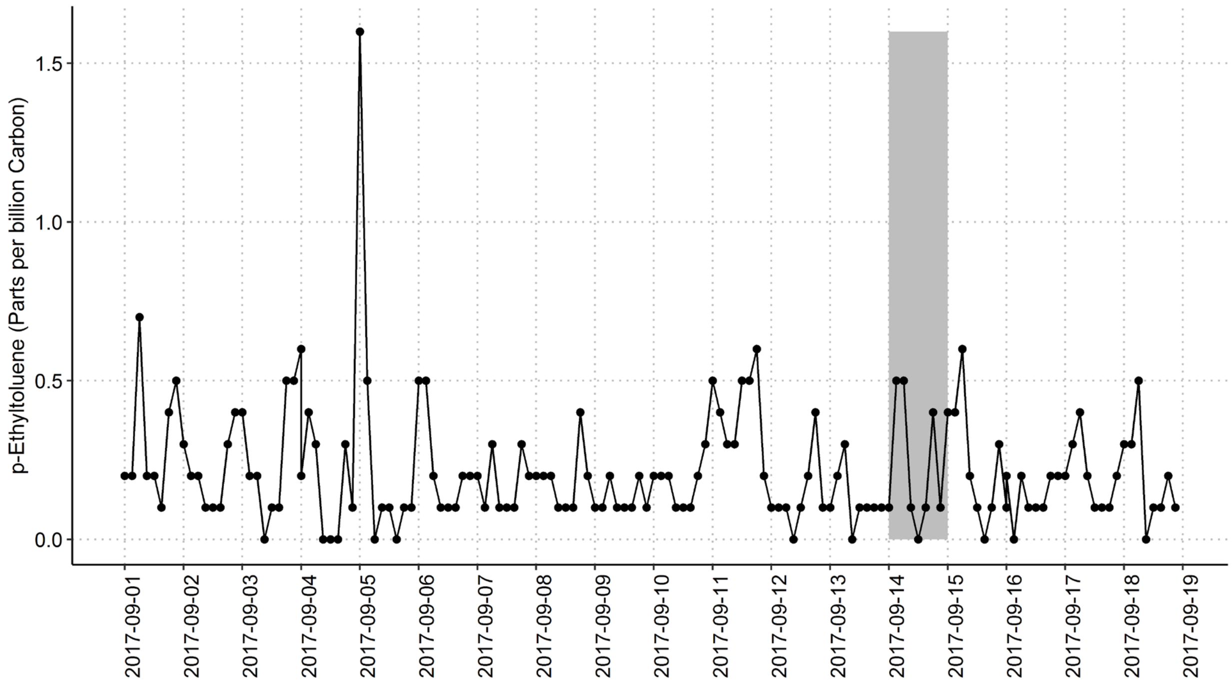

Figure B-25. p-Ethyltoluene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

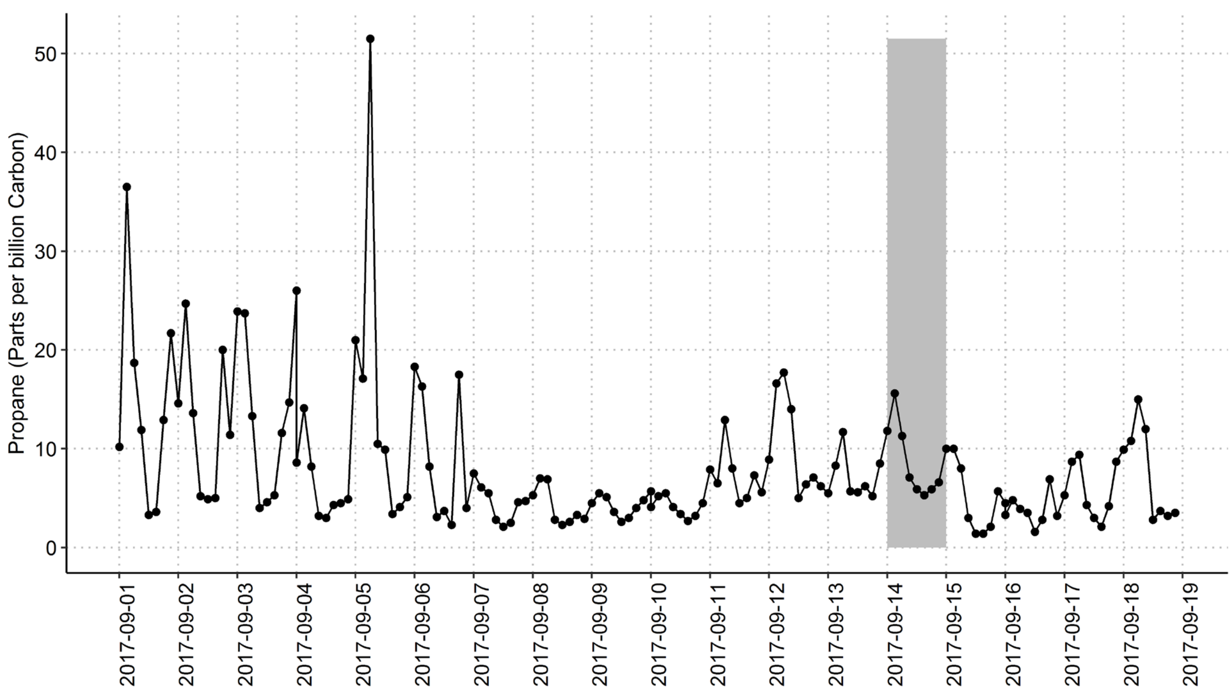

Figure B-26. Propane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

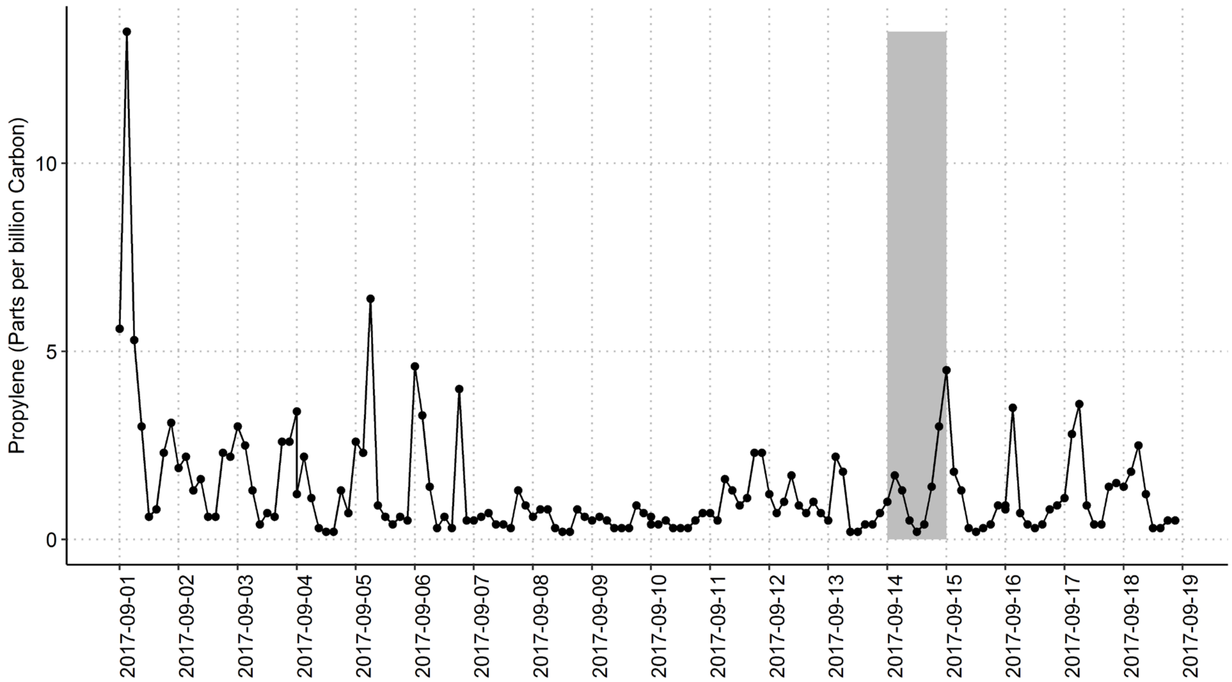

Figure B-27. Propylene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

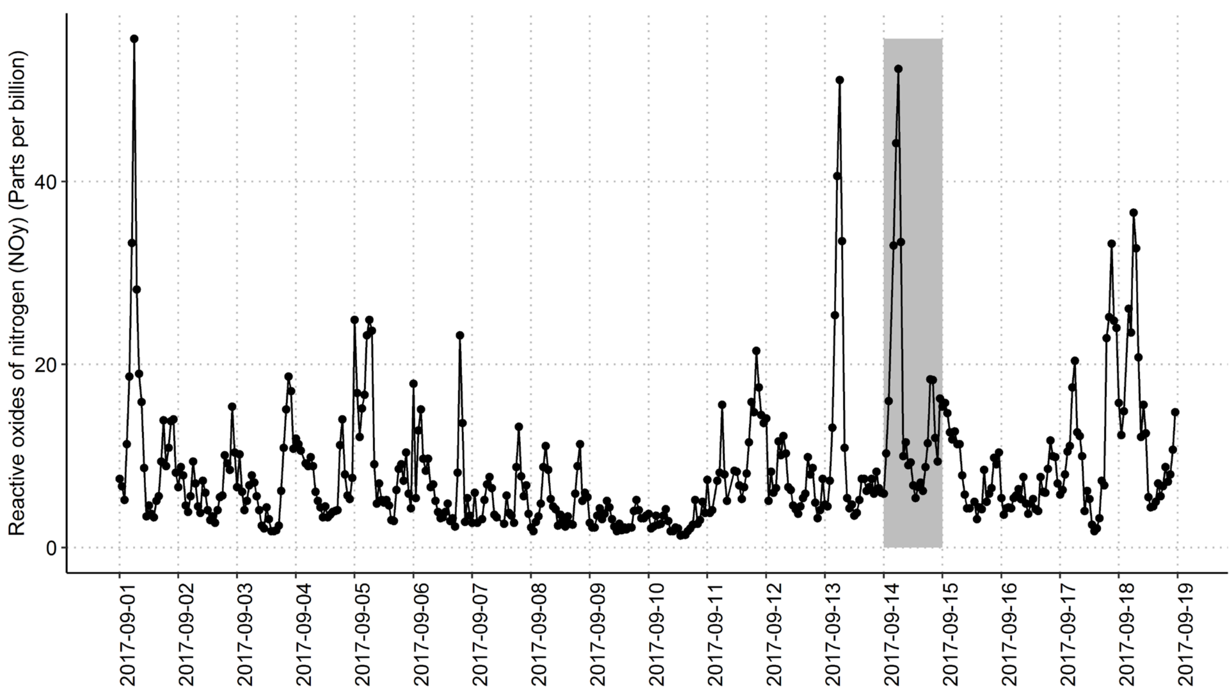

Figure B-28. Reactive oxides of nitrogen (NO_y) measurements at the Capitol monitoring site from September 1 through September 18, 2017.

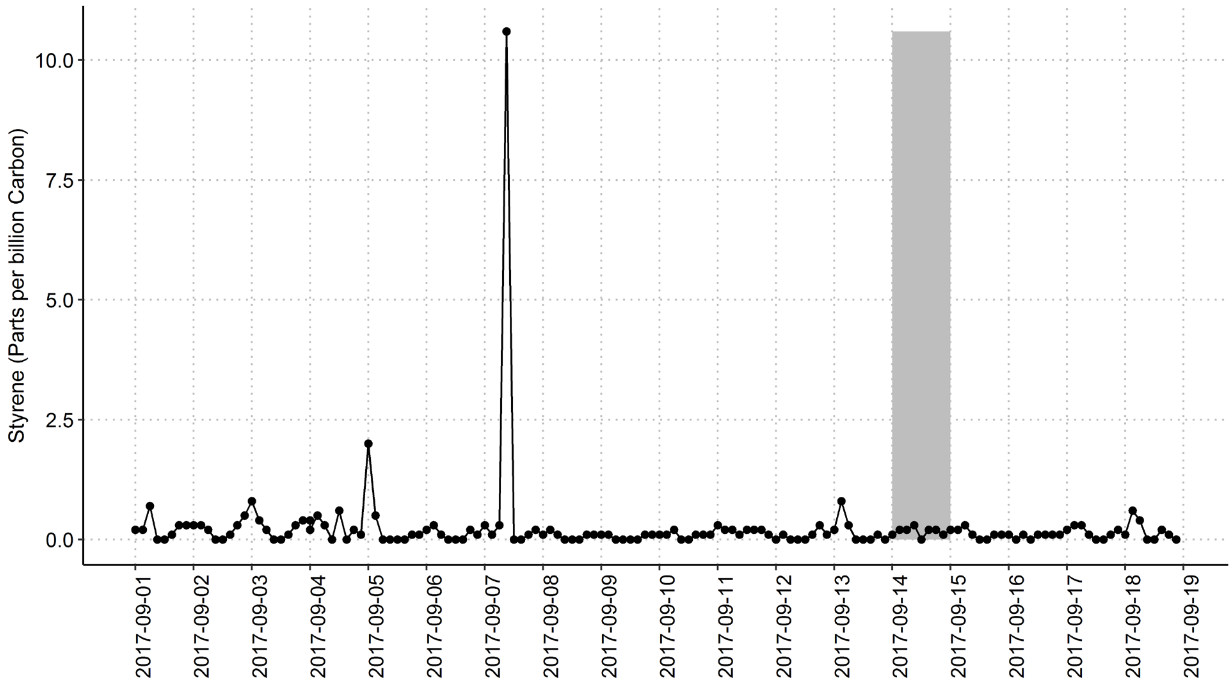

Figure B-29. Styrene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

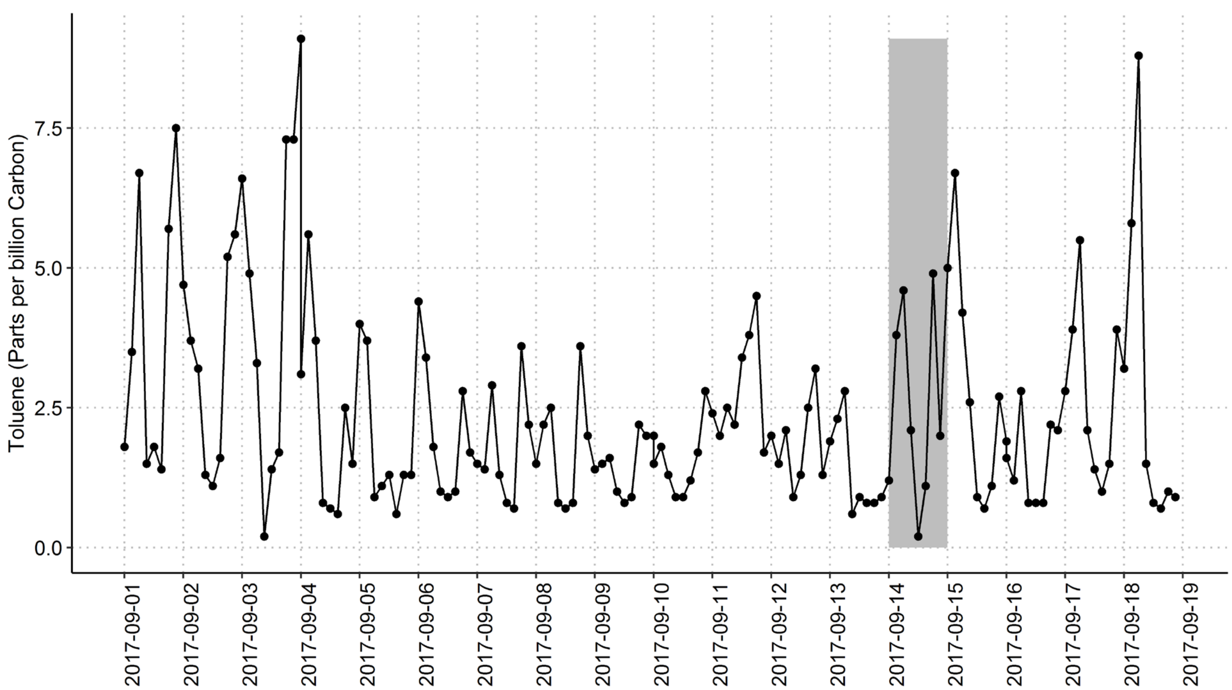

Figure B-30. Toluene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

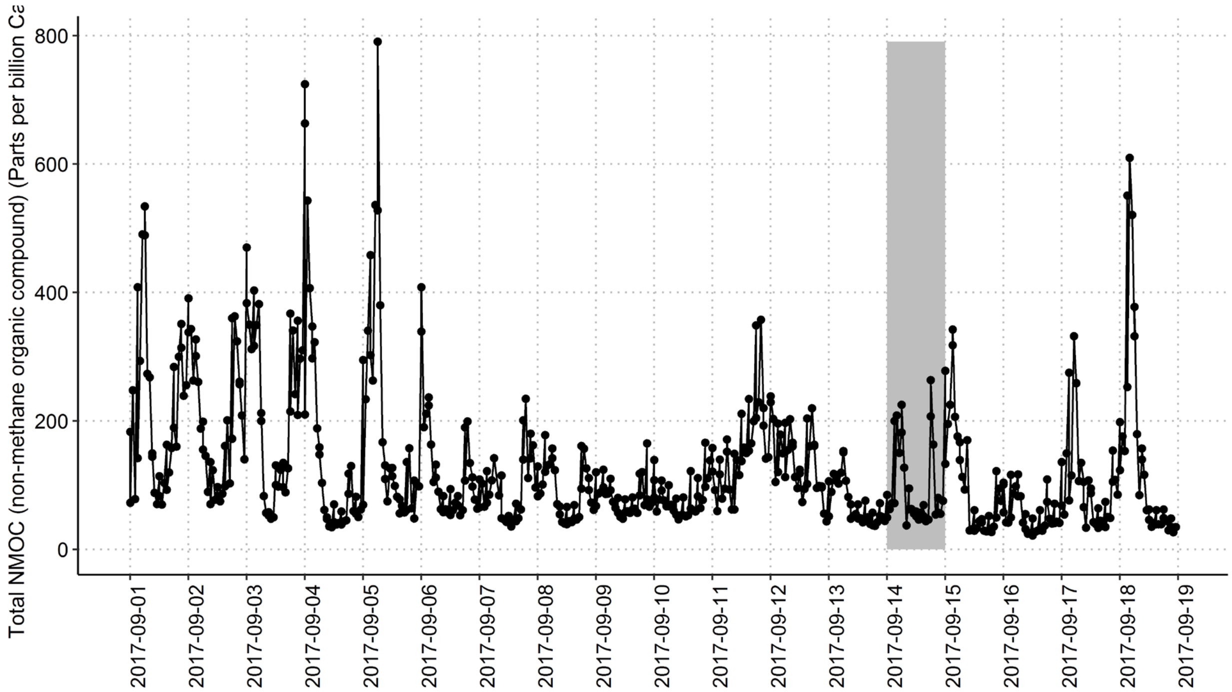

Figure B-31. Total non-methane organic compound measurements at the Capitol monitoring site from September 1 through September 18, 2017.

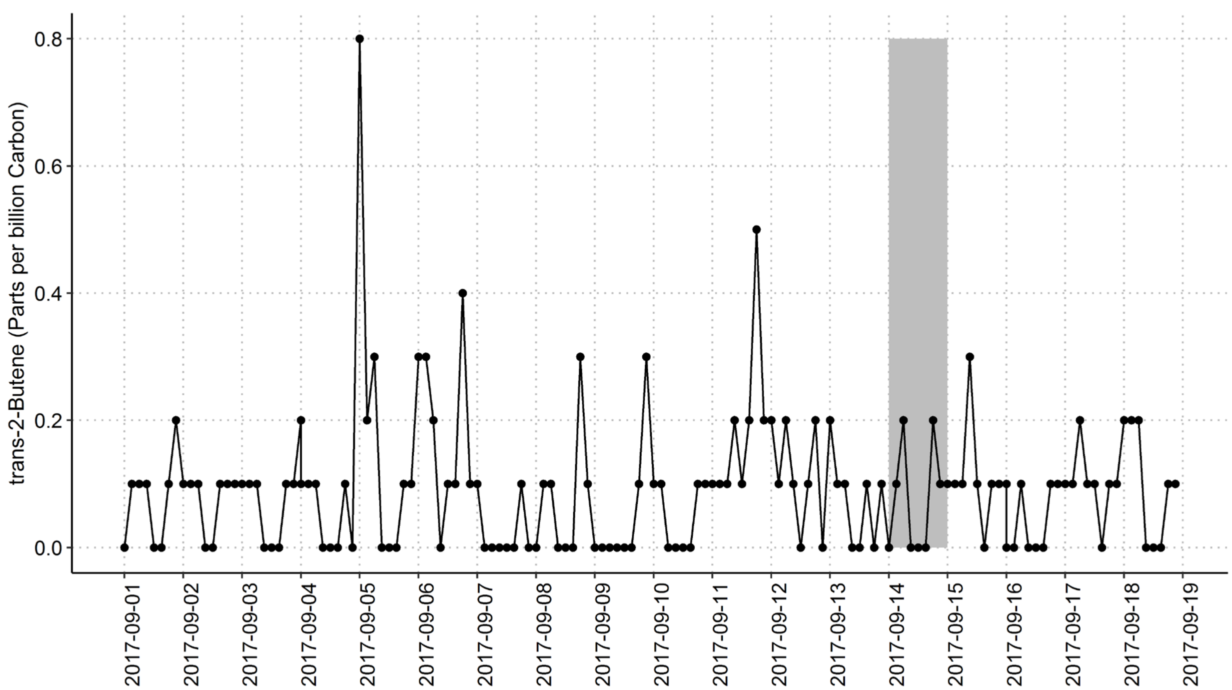

Figure B-32. Trans-2-butene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

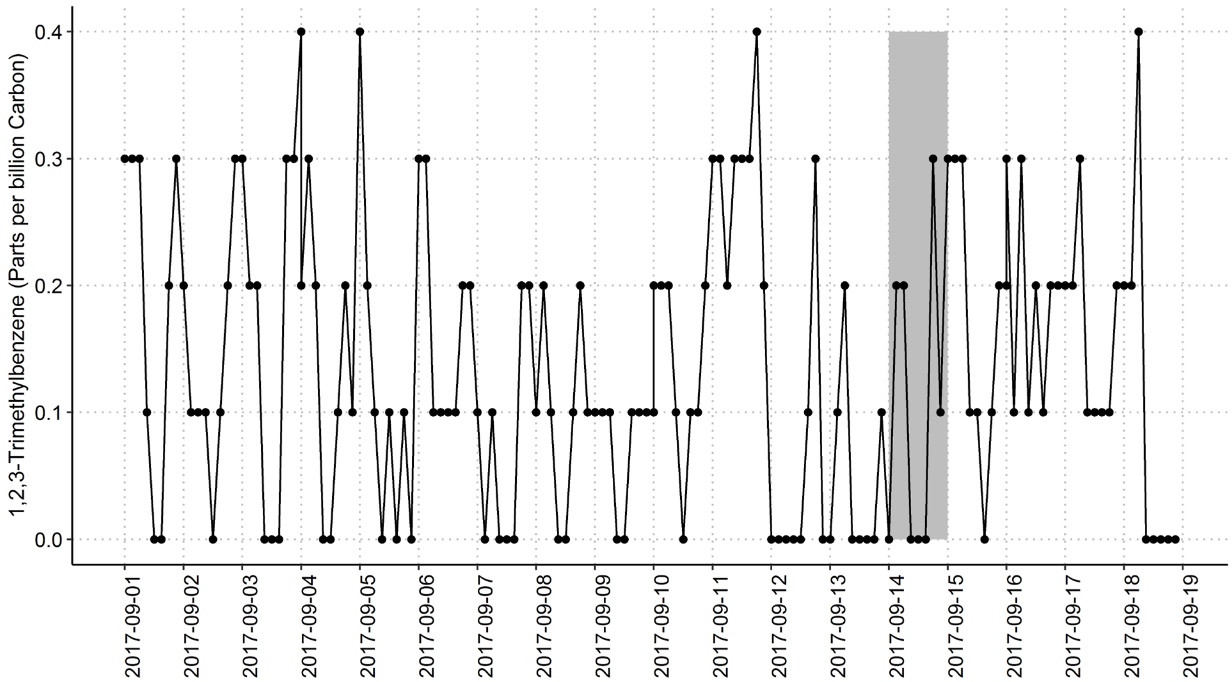

Figure B-33. 1,2,3-Trimethylbenzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

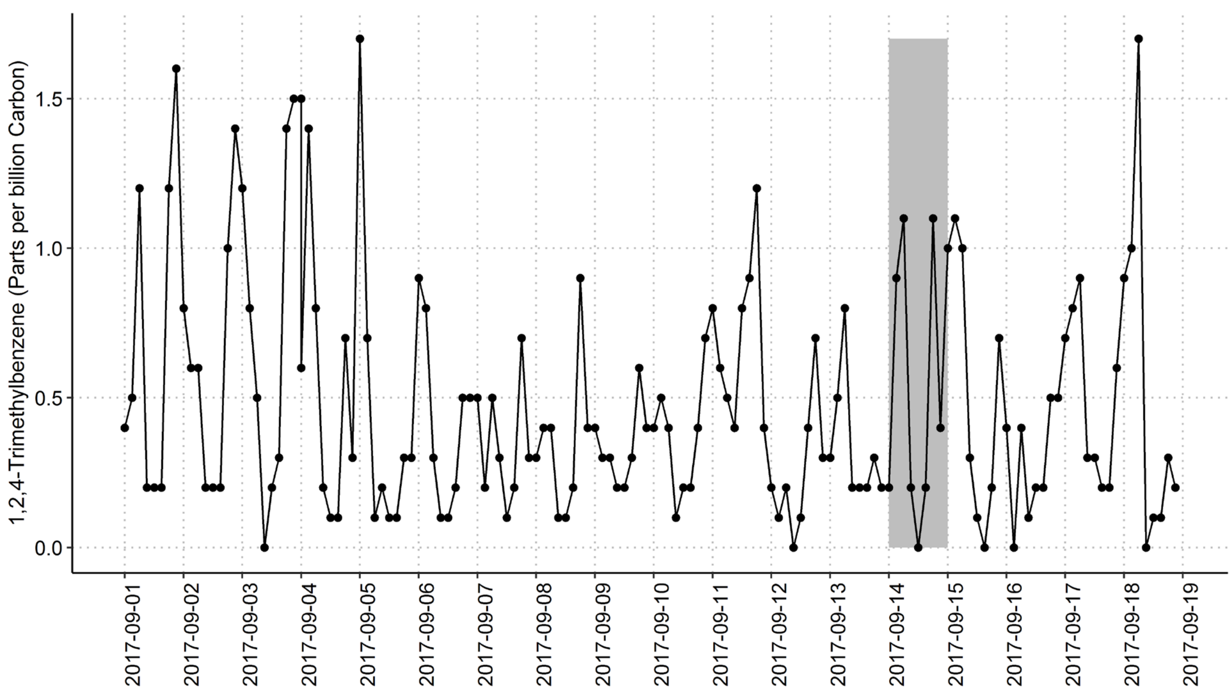

Figure B-34. 1,2,4-Trimethylbenzene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

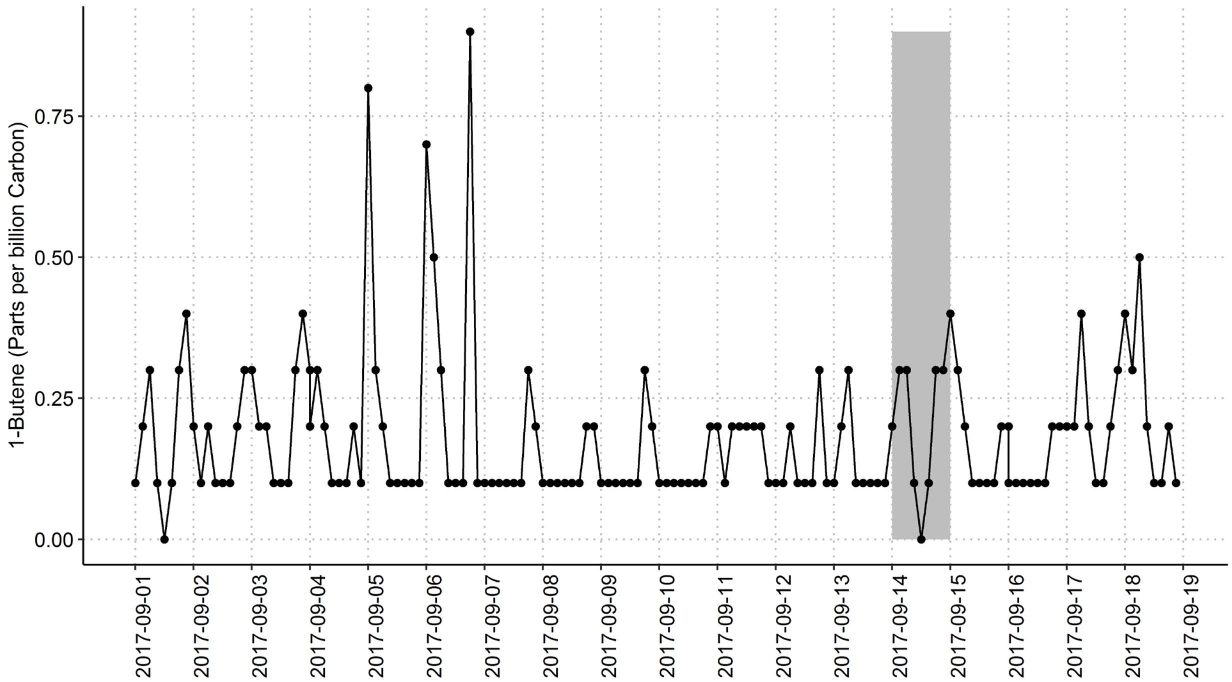

Figure B-35. 1-Butene measurements at the Capitol monitoring site from September 1 through September 18, 2017.

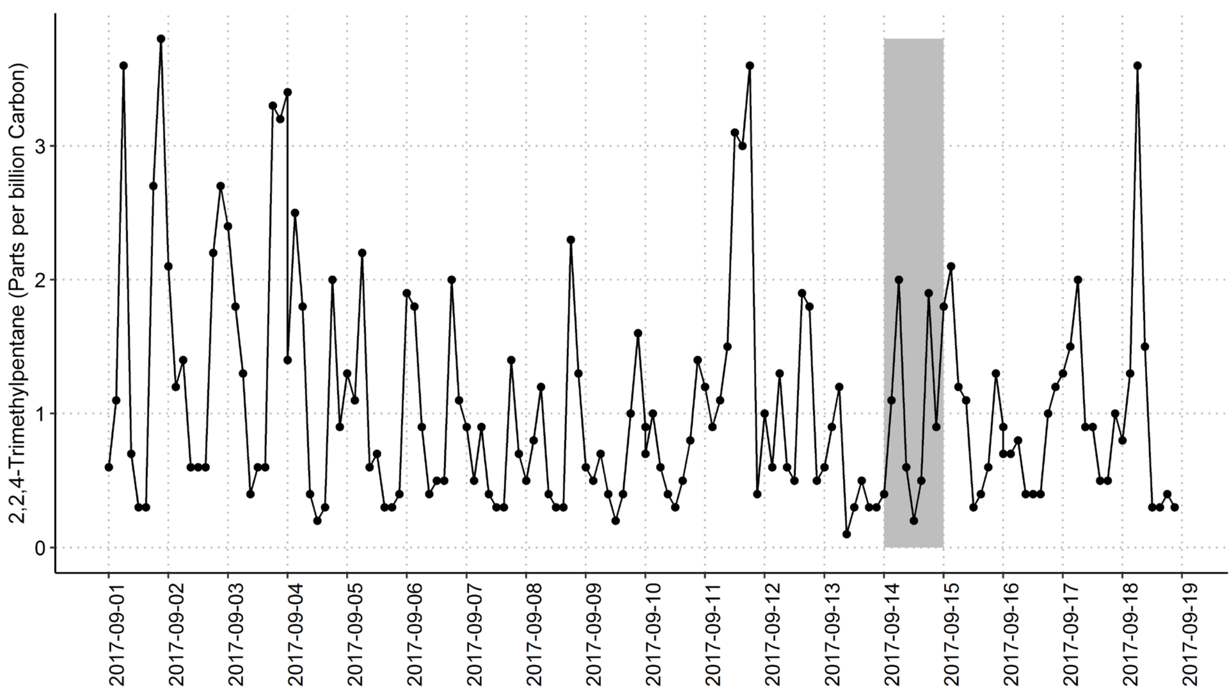

Figure B-36. 2,2,4-Trimethylpentane measurements at the Capitol monitoring site from September 1 through September 18, 2017.

Appendix C. Coarse Resolution Photochemical Modeling With and Without Fire Emissions

Figure C-1 shows the BlueSky Gateway model's estimated impacts of fires in the United States on peak 8-hr average ozone concentrations at the surface on September 14, 2017. This result indicates qualitatively that ozone concentrations in Louisiana were impacted by smoke on September 14.

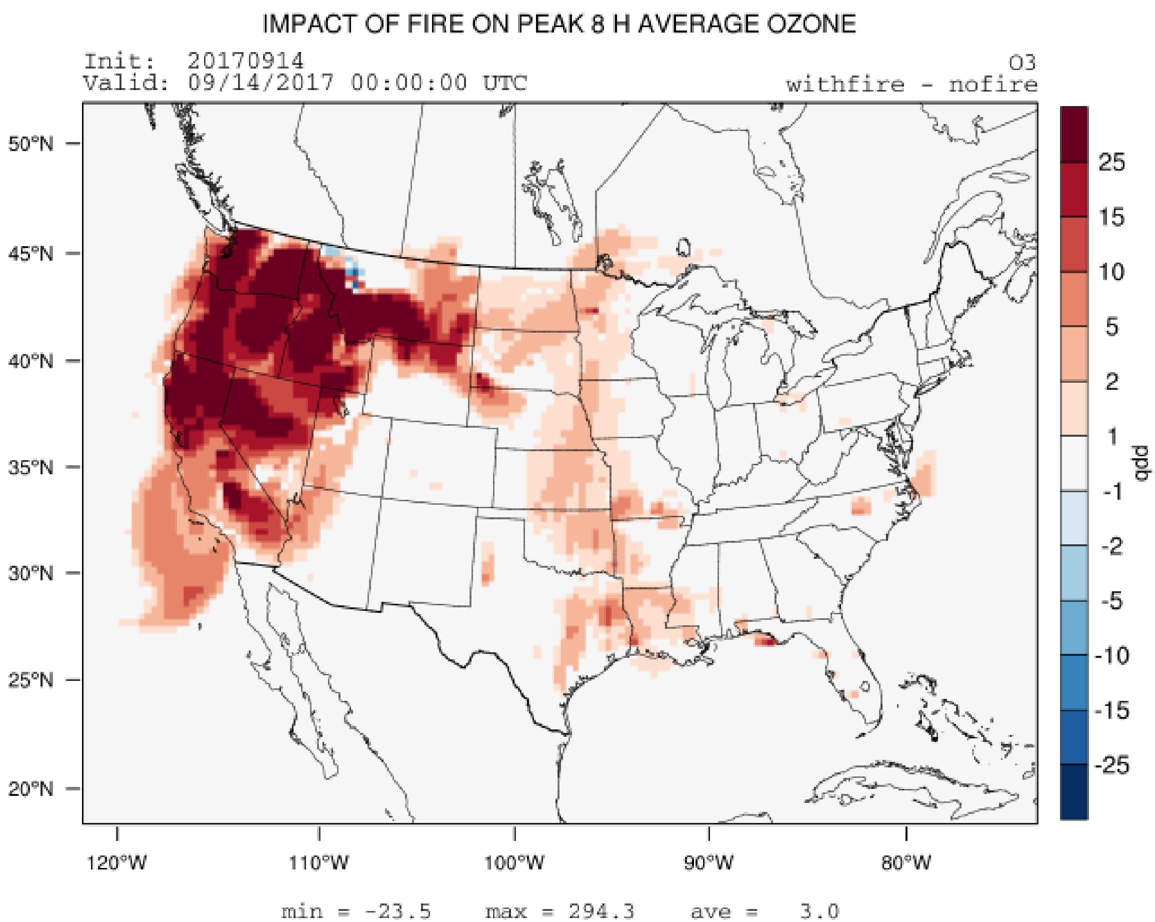

Figure C-1. Impact of fires within the United States on peak 8-h average ozone concentrations on September 14, 2017. Given the operational forecast nature of BlueSky Gateway, these results are best interpreted as a qualitative indicator of potential smoke impacts rather than as a quantitative measure of ozone present due to smoke.

BlueSky Gateway (Craig et al., 2007; Strand et al., 2012) is an operational air quality forecasting system developed by STI in collaboration with the USDA Forest Service to predict nationwide air quality impacts due to wildfires and other emission sources at 36-km resolution. BlueSky Gateway components include the BlueSky Framework for estimating fire emissions; the Pennsylvania State University/National Center for Atmospheric Research's Mesoscale Model (MM5) for predicting meteorological conditions; the Community Multiscale Air Quality (CMAQ) model for predicting gaseous and particulate pollutant concentrations; and the Sparse Matrix Operator Kernel Emissions (SMOKE) processing system for incorporating emissions. Simulations are initialized daily at 0000 GMT (00Z).

Daily fire locations and sizes are provided by the Satellite Mapping Automatic Reanalysis Tool for Fire Incident Reconciliation (SmartFire) (Raffuse et al., 2013), which integrates and reconciles satellite-detected fire data from the National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) analyses into BlueSky Gateway. The BlueSky Framework was used to develop emissions estimates from the SmartFire burn area predictions. This methodology is similar to that currently used by the EPA for developing national fire emission inventories (Sullivan et al., 2009). Non-fire anthropogenic emissions from the National Emission Inventory are prepared for air quality modeling and merged with the fire emissions inputs using SMOKE.

Two CMAQ air quality simulations are run within the BlueSky Gateway each day. Simulations are run with and without smoke emissions. The purpose of this second simulation is to estimate the impact of fire emissions on ozone concentrations. The difference between the ozone concentrations modeled with and without fire emissions is calculated by subtracting the fire emissions model results from the model results without fire emissions. For retrospective purposes such as exceptional event demonstrations, additional information and computational approaches could be used to improve results. Therefore, for purposes of this report, the BlueSky Gateway results are best interpreted as a qualitative indicator of potential smoke impacts rather than as a quantitative measure of ozone present due to smoke.

References

Craig K.J., Wheeler N.J.M., Reid S.B., Gilliland E.K., and Sullivan D.C. (2007) Development and operation of national CMAQ-based $PM_{2.5}$ forecast system for fire management. Presented at the *6th Annual CMAS Conference, Chapel Hill, NC, October 1-3,* by Sonoma Technology, Inc., Petaluma, CA. STI-3228.

Raffuse S.M., Larkin N.K., and Dedecko T.M. (2013) SmartFire 2: a flexible framework for merging fire information. Presented at the *4th Fire Behavior and Fuels Conference, Raleigh, NC, February 21,* by Sonoma Technology, Inc., Petaluma, CA. STI-5467.

Strand T.M., Larkin N., Craig K.J., Raffuse S., Sullivan D., Solomon R., Rorig M., Wheeler N., and Pryden D. (2012) Analysis of BlueSky Gateway $PM_{2.5}$ predictions during the 2007 southern and 2008 northern California fires. *J. Geophys. Res*, 117(D17301), doi: 10.1029/2012JD017627. Available at http://onlinelibrary.wiley.com/doi/10.1029/2012JD017627/pdf.

Sullivan D.C., Du Y., and Raffuse S.M. (2009) SMARTFIRE- and BlueSky-enabled methodology for developing wildland fire emission inventories for 2006-2008. Technical memorandum prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC, by Sonoma Technology, Inc., Petaluma, CA, STI-905517-3714, October.

Appendix D. Meteorological Conditions

The upper-level weather pattern, surface weather pattern, and local meteorological conditions observed on September 13 and 14, 2017, suggest smoke transport, vertical mixing, and smoke accumulation in the Baton Rouge area.

Upper-Level Weather Pattern

Pressure patterns aloft can be used to determine regional atmospheric stability. In particular, 500-mb maps—which display height contours with winds at roughly 18,000 feet above sea level—are used to identify

- Ridges of high pressure, which are associated with a stable atmosphere with reduced vertical mixing.
- Troughs of low pressure, which are associated with an unstable atmosphere and enhanced vertical mixing.
- Aloft wind patterns that may indicate long-range pollutant transport.

On September 13, 2017, an upper-level trough of low pressure associated with the remnants of Hurricane Irma enhanced atmospheric mixing over the southeastern U.S. (**Figure D-1**). This mixing allowed aloft smoke to reach the lower levels of the atmosphere. Discussion of aloft winds and transport is provided in the Aloft Smoke Transport section in this appendix.

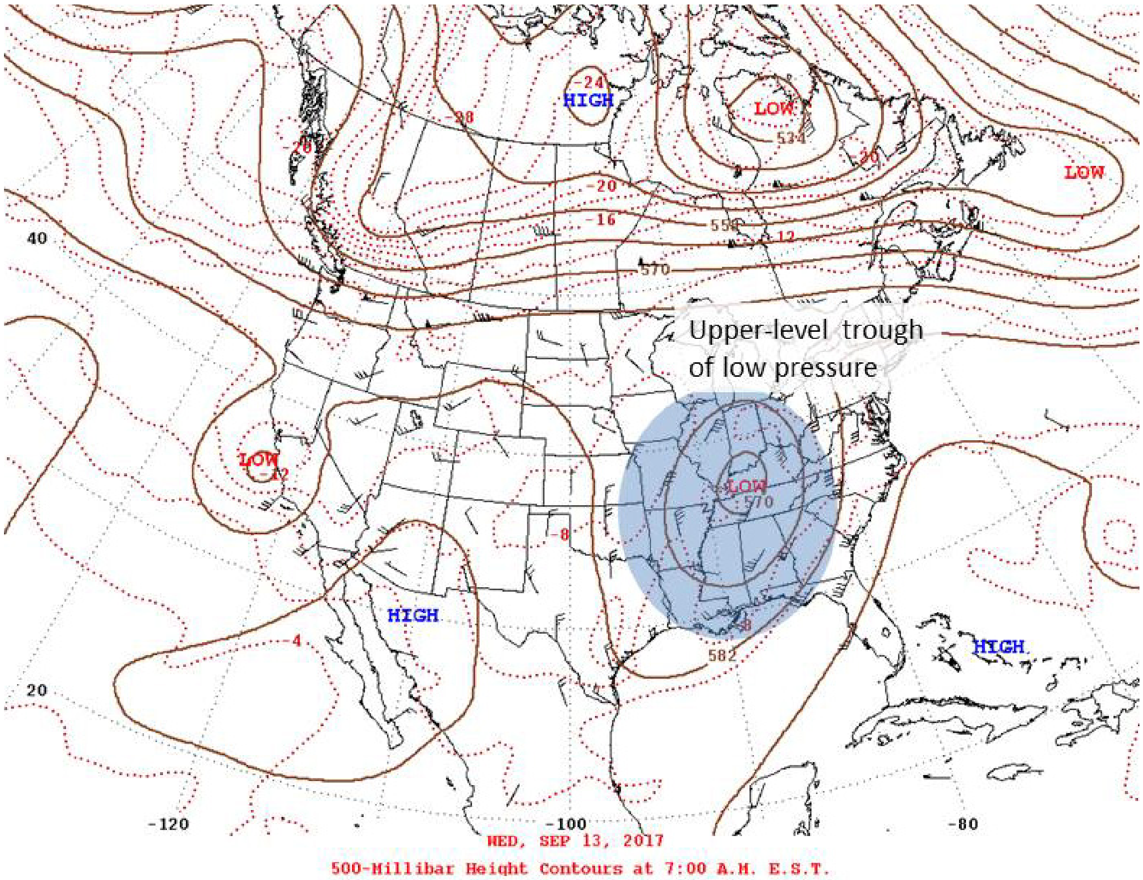

Figure D-1. Upper-level weather pattern on September 13, 2017. Contours indicate 500-mb heights and regions of aloft high pressure and low pressure. Source: http://www.wpc.ncep.noaa.gov/dailywxmap/.

On September 14, 2017, an upper-level ridge of high pressure reduced atmospheric mixing over Louisiana, trapping pollutants near the ground (**Figure D-2**). Under these stable conditions, smoke that had mixed down from aloft on September 13 or earlier would have been confined in the lower atmosphere. This ridge also produced partly to mostly sunny skies and temperatures in the mid- to upper-80s in Baton Rouge. These weather conditions supported the formation of ground-level ozone.

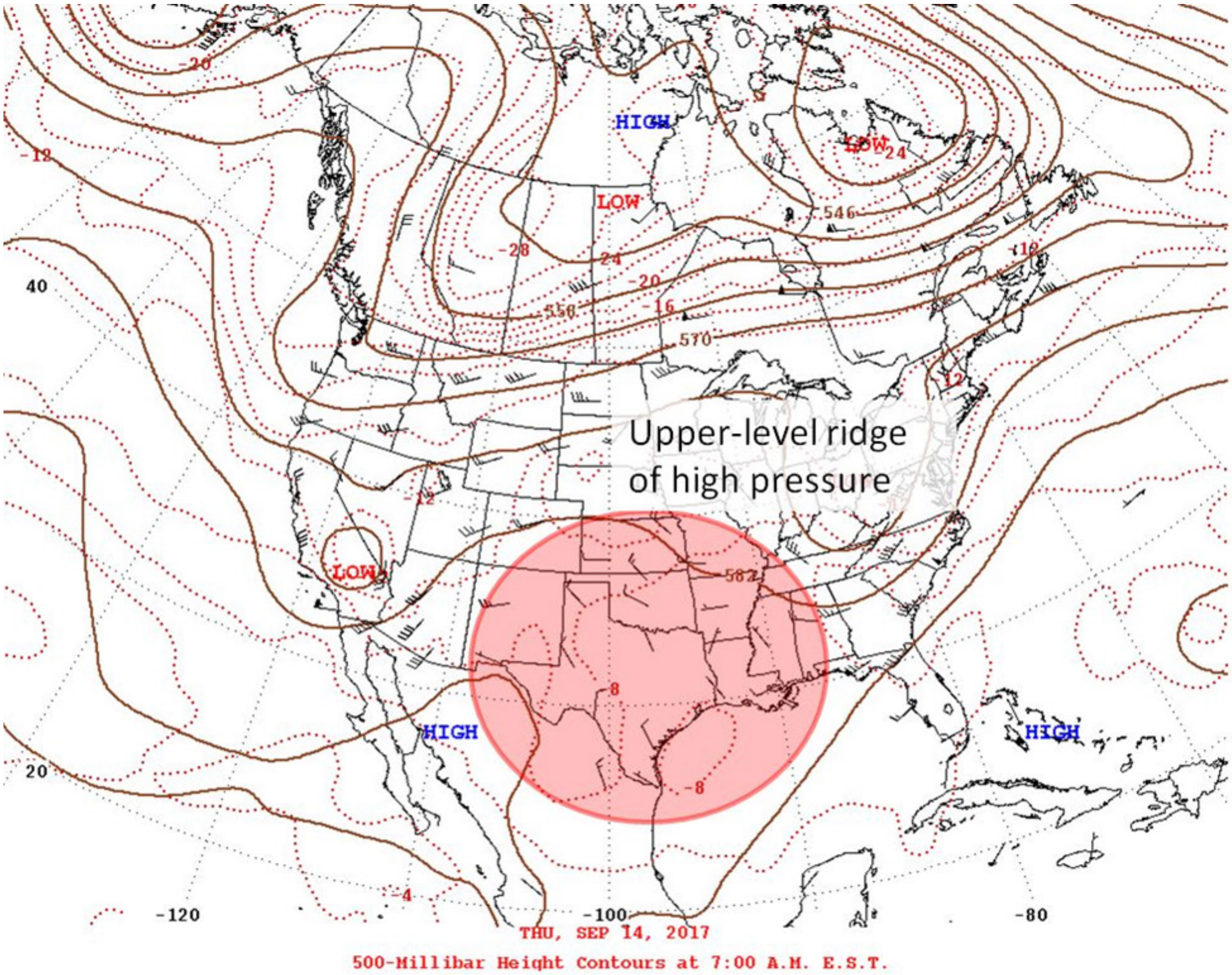

Figure D-2. Upper-level weather pattern on September 14, 2017. Contours indicate 500-mb heights and regions of aloft high pressure and low pressure. Source: http://www.wpc.ncep.noaa.gov/dailywxmap/.

Surface Weather Pattern and Winds

On September 14, 2017, surface high pressure over the southeastern U.S. produced light winds in Baton Rouge, reducing horizontal pollutant dispersion and allowing pollutants to accumulate (**Figure D-3**).

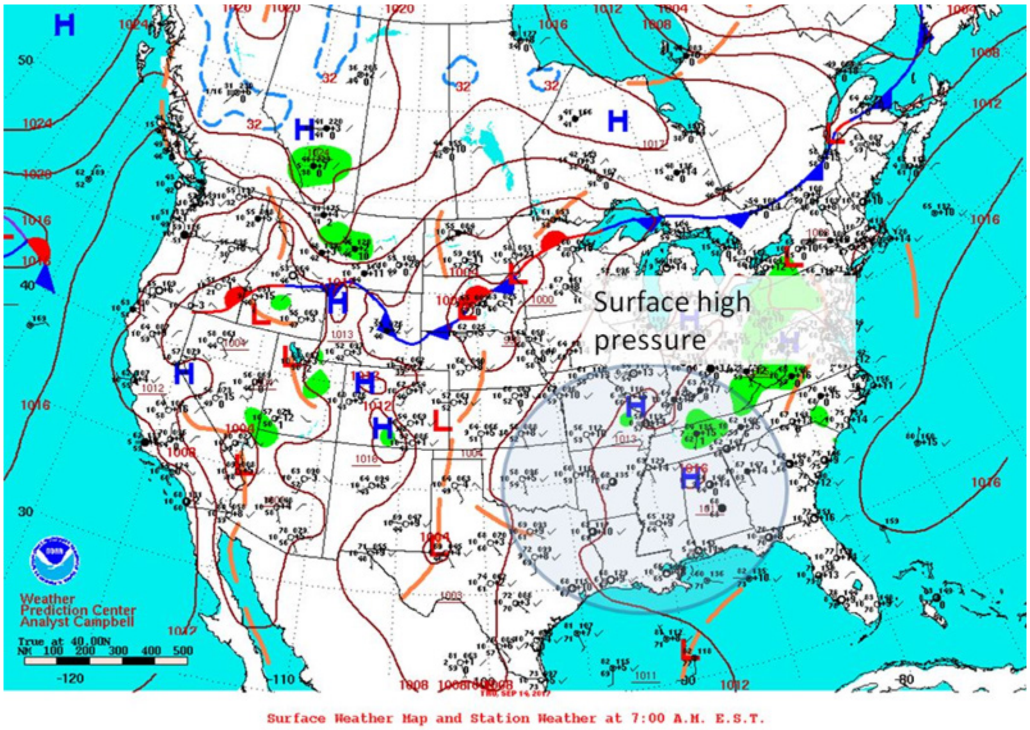

Figure D-3. Surface weather map for September 14, 2017. Contours indicate sea level pressure. Source: http://www.wpc.ncep.noaa.gov/dailywxmap/.

Aloft Smoke Transport

Although surface winds were light on September 13 and 14, aloft winds (at 500 mb, or approximately 18,000 feet above sea level) over the previous days indicated potential smoke transport from wildfires in the Pacific Northwest toward the Northern Plains and south toward the Gulf Coast. The upper-level wind pattern shown in **Figure D-4** for the afternoon of September 13 is consistent with this long-range transport path.

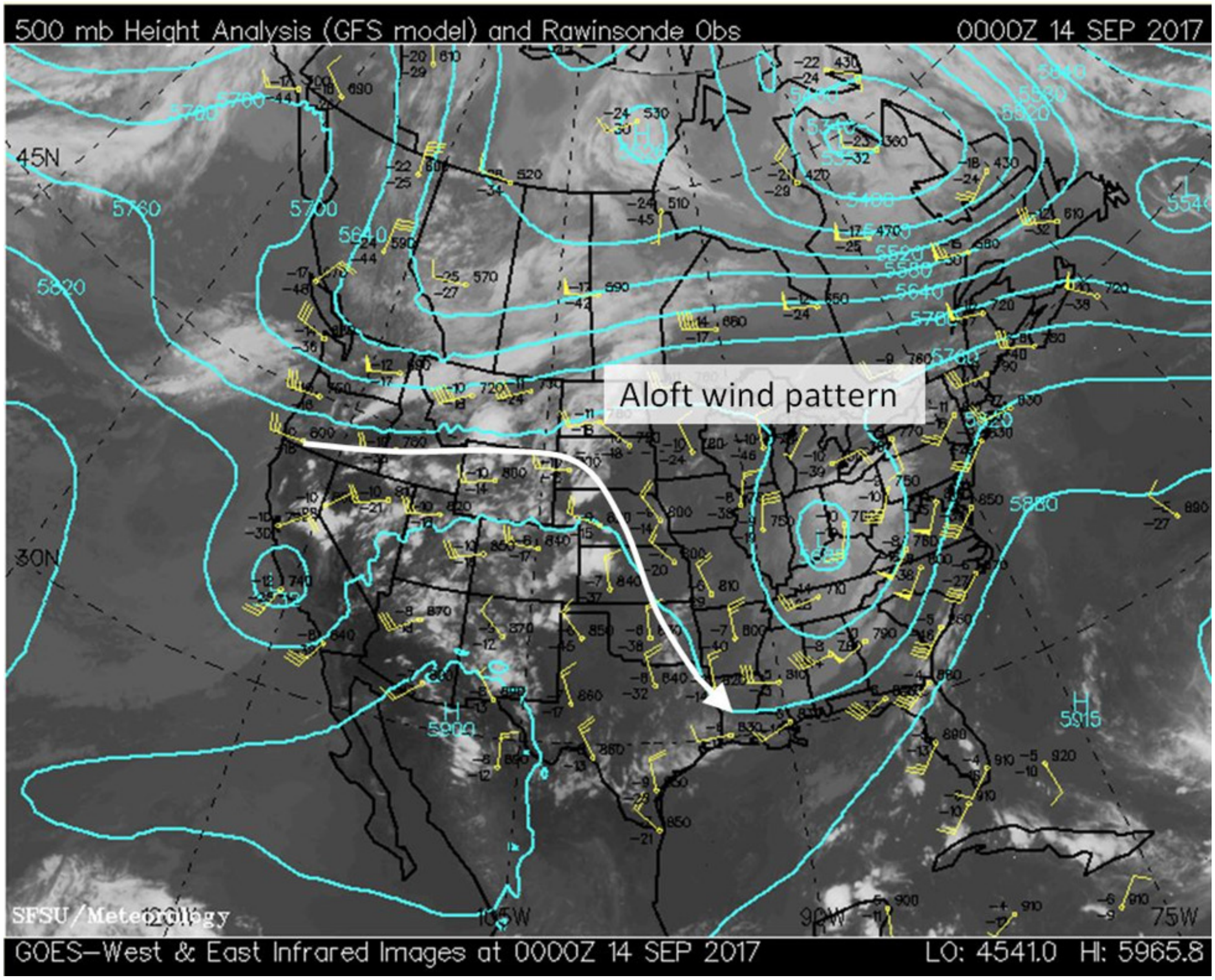

Figure D-4. Aloft (500-mb) wind pattern on the afternoon of September 13, 2017. Wind barbs (yellow) indicate upper-level transport from the Pacific Northwest to the east over the Northern Plains and south toward the Gulf Coast. Source: http://squall.sfsu.edu/scripts/sathts_500_archloop.html.

Local Weather Conditions in Baton Rouge

In addition to the stable upper-level weather pattern on September 14 which limited atmospheric mixing over Louisiana, local weather conditions in Baton Rouge were favorable for pollutant accumulation and ozone formation. Specifically, surface winds were light and variable throughout the day, reducing pollutant dispersion. Figure D-5 shows time series for wind speed and direction at the Baton Rouge Metropolitan Airport, Ryan Field (KBTR). The hours shown without wind speed data (top chart) are indicative of calm conditions. The variable wind directions during the other hours (bottom chart) allowed for pollutant recirculation and accumulation.

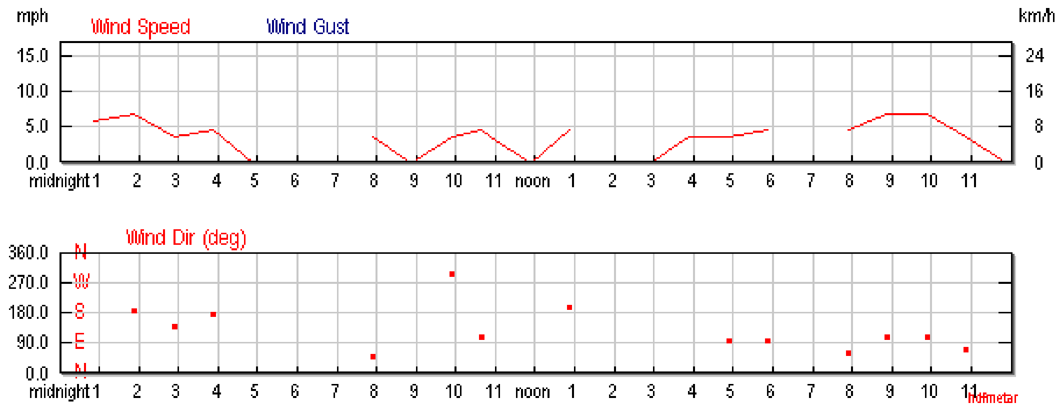

Figure D-5. Observed winds at KBTR on September 14, 2017, showing wind speeds (top chart) in mph and wind direction (bottom chart) in degrees from north. Source: http://www.wunderground.com.

Warm temperatures and sunny skies enhance the formation of ground-level ozone. The maximum temperature recorded at KBTR on September 14 was 88°F, which is about normal for mid-September in Baton Rouge. Skies were partly to mostly sunny throughout the day. However, cloud development may have reduced ozone production slightly (Figure D-6) during the midday and afternoon hours, which are typically peak production hours for ozone.

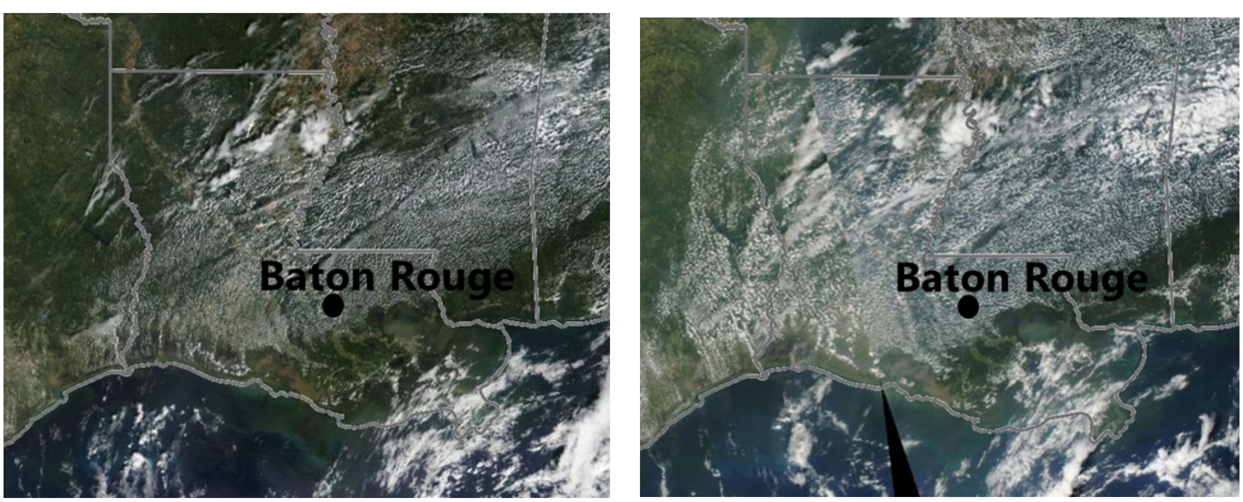

Figure D-6. Moderate Resolution Imaging Spectroradiometer (MODIS) Terra (left) and Aqua (right) visible satellite imagery on September 14, 2017, at approximately 11:00 a.m. and 12:30 p.m., respectively. Midday cloud development may have limited ozone production. Source: https://modis.gsfc.nasa.gov/.